A STUDY ON PHYTOPLANKTON PIGMENTS AND PRIMARY PRODUCTIVITY IN THE COCHIN BACKWATER DURING SOUTH-WEST MONSOON

DISSERTATION SUBMITTED BY

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CERTIFICATE

This is to certify that this Dissertation is a bonafide record of the work done by **Miss Preetha Paul** under my supervision and that no part thereof has been presented before for any other degree.

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P R E F A C E

This dissertation is mainly centered around the aspects of phytoplankton pigments and primary productivity in relation to the environmental characteristics of the Ernakulam channel close to the barmouth of Cochin backwater system during south-west monsoon season.

The phytoplankters, being the primary producers in the food-chain and food-web of marine and estuarine ecosystems, are of considerable importance in the larval recruitment of major fisheries of estuarine and coastal waters. The phytoplankton serves as primary food resource in the earlier stages of the life cycle of marine and estuarine organisms during their planktonic phase of life.

As the euphotic zone is considerably less in the Cochin backwater, a good part of phytoplankton production, while sinking below the euphotic zone, could serve as food for herbivorous fishes and other benthic communities; and the other direct link is through the detritus at the bottom of estuary; while a considerable portion of this production is transported to the neighbouring environment by physical and biological processes, such as tides and migration of consumers. Thus the magnitude of primary production in the Cochin backwater is able to sustain a very rich biota of organisms feeding at different trophic levels.

The environmental factors play a vital role in the production and ecology of the primary and secondary producers in the estuarine ecosystem. The Cochin backwater system is the largest of its kind in the southwest coast of India as well as the most affected ecosystem in the recent years by human interferences.

The main objectives of the present investigation are to obtain accurate and up-to-date information on the concentrations of different phytoplankton pigments (live and dead) influencing primary production, their distribution pattern, relative abundance and quantitative assessment; and to study the influence of monsoon-related hydrographic parameters on phytoplankton pigments and primary productivity during the southwest monsoon season.

This comprehensive study was planned since no work of such detailed nature is available in literature, from this estuarine waterbody adjoining Cochin city since 1976. The significance of the study of phytoplankton pigments and primary productivity, resume of relevant literature and scope of the study are given under the title "INTRODUCTION". The description of Cochin backwater environment, study area and station positions, methodology in the collection of samples, laboratory analysis and treatment of data are included in "MATERIAL AND METHODS".

The "RESULTS" and "DISCUSSION" of the dissertation embody sections relating to (1) the environment, (2) major phytoplankton groups, (3) phytoplankton pigments, (4) primary productivity, (5) relative abundance, (6) quantitative assessment of productivity potential, and (7) influence of hydrography on phytoplankton pigments and primary productivity.

The salient features and findings of the present investigation are given in "SUMMARY", followed by the "REFERENCES" which include the relevant literature cited in this dissertation.

I wish to express my deep sense of gratitude to my supervising teacher Mr. G.S. Daniel Selvaraj, Scientist (S.G), C.M.F.R.I., Cochin for his constant advice, inspiring guidance and whole-hearted support throughout the course of this study and in the preparation of the manuscript. I express my sincere thanks to Dr. P.S.B.R. James, Director, C.M.F.R.I., Cochin for all the facilities provided. I am thankful to Mr. D.S. Rao, Semester-in-charge for providing necessary facilities to carry out this work. I am much obliged to Dr. A. Noble, Principal Scientist for his valuable suggestions and encouragement. I wish to thank Mr. V.K. Balachandran for helping in the identification of phytoplankton groups. I express my gratitude to Mr. T.V. Satyanandan, Scientist for the help rendered in statistical analysis.

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INTRODUCTION

It is well known that all life in the aquatic environment depend primarily on the conversion of carbon and nitrogen into protoplasm. It can be accomplished by the living plants through photosynthesis. Though the higher algae and certain flowering plants have dominant role in the production of organic matter in the shallow estuarine and coastal regions, phytoplankters are the major producers in the marine and coastal waterbodies, since the amount of photosynthesis going on in these microflora is many times greater than the total production of all other types of vegetation in the aquatic ecosystem. Thus, the phytoplankters are important flora on account of their supreme status in the aquatic food-chain and food-web as primary producers.

Apart from the different methods adopted for the quantitative estimation such as cell count, measurement of oxygen and estimation of primary productivity in the euphotic column through incubation experiments, chlorophyll measurements are indicative of bioproductivity in the aquatic ecosystems. Although there are several pigments involved in the photosynthetic process, the fundamental role is played by chlorophylls; of which chlorophyll 'a' is the major pigment in phytoplankton which is able to transform light energy directly into chemically bound energy; and the light energy absorbed by the other pigments including chlorophyll 'b' and 'c' may be converted via. chlorophyll 'a' (Rabinowitch, 1951). However, it appears suitable as a measure of production irrespective of variation in cell counts from place to place; and Ryther and Yentsch (1957) have recommended the use of chlorophyll concentration for estimating primary production in space and time. But, while relating the chlorophyll pigments with primary productivity, one should be aware of the presence of inactive/less active chlorophyll pigments and phaeo-pigments within the euphotic column as well as below the euphotic column in the estuarine and coastal ecosystems.

The fishery resources of any aquatic system mainly depend on the magnitude of primary and secondary producers which in turn are influenced by various physical, chemical and biological factors. The study of phytoplankton pigments and primary production in the estuarine and coastal ecosystems is also of considerable significance in the larval recruitment of the major fisheries of this region, as the larvae at the time of hatching and during their initial critical phase of growth feed on these microscopic phytoplankton in sufficient concentration for their survival; and the study of the distribution and abundance of these microflora will enable the prediction of the survival and recruitment of larvae in the multi-specific fishery of tropical environment.

The phytoplankton distribution and primary productivity vary considerably in the estuarine ecosystem in space and time. Although fairly good amount of information is available in literature on taxonomy, biology, physiology, distribution, abundance and blooms of phytoplankton, seasonal accounts on phytoplankton pigments and primary productivity from the estuarine ecosystems in relation to hydrological parameters are limited especially during the southwest monsoon season. The southwest monsoon plays a vital role on the estuarine ecosystem by the influx of nutrient-rich fresh water discharge from rivers and land drainage and by considerable admixture of nutrient-rich saline water by the coastal upwelling process resulting in highly complex dynamic environment.

The Cochin backwater is one such unique estuarine ecosystem influenced by the southwest monsoon during June-September, resulting in wide fluctuations in the environmental parameters like light penetration, temperature, salinity, dissolved oxygen, nutrients and in the species composition and succession of mainly primary and secondary producers. Such drastic changes in the environment, in turn, considerably influence the organic production of the ecosystem.

A perusal of literature on the phytoplankton and primary productivity from the estuaries revealed that the pioneering work on the ecology and seasonal succession of diatom flora of the estuarine waters of India was that of Iyangar and Venkataraman (1951) for the Cooum estuary in Madras; Seshadri (1957) studied the seasonal organic production in relation to environmental features in Zuari and Mandovi estuaries; Krishnamurty (1971) and Krishnamurty and Sundararaj (1973) studied the phytoplankton pigments in Porto Novo waters; Krishnamurty and Purushothaman (1971) studied the diurnal variation in phytoplankton pigments in the Vellar estuary; Krishnamurty and Santhanam (1974) and Santhanam et al. (1975) gave descriptive accounts of species distribution and quantitative ecology of phytoplankton from the same region; and Mani et al. (1986) described the ecology of phytoplankton blooms in the Vellar estuary.

In the Cochin backwaters, phytoplankton studies were pertaining to plant pigments (Qasim and Reddy, 1967), organic production (Qasim et al., 1969), salinity tolerance of phytoplankton (Qasim et al., 1972), seasonal abundance of phytoplankton (Gopinathan, 1972), spatial and temporal distribution of phytoplankton (Gopinathan et al., 1974; Joseph and Pillai, 1975), growth characteristics of phytoplankton (Joseph and Nair, 1975), primary productivity of the entire estuarine system (Nair et al., 1975), quantitative ecology of phytoplankton (Gopinathan et al., 1984) and phytoplankton distribution (Jayalakshmi et al., 1986).

While the physico-chemical features of the Cochin backwater were studied by several authors (Balakrishnan, 1957; Ramamirtham and Jayaraman, 1963; Cherian, 1967; Josanto, 1971; Wellershaus, 1973; and Sankaranarayanan et al., 1986), special emphasis was given on light penetration in estuary by Qasim *et al*. (1968) and on nutrient distribution by Sankaranarayanan and Qasim (1969), Manikoth and Salih (1974) and Balakrishnan and Shynamma (1976). Diurnal observations on the physico-chemical features of Cochin backwater were studied in relation to tides (George and Kartha, 1963; Qasim and Gopinathan, 1969; Shynamma and Balakrishnan, 1973), Zooplankton (Pillai and Pillai, 1973) and prawn seed abundance (MPEDA, 1980; Sheeba Susan Mathews, 1987).

The available literature bring to the notice that very little work has been done in the past ten to fifteen years on the phytoplankton production and distribution coupled with environmental characteristics in the Cochin backwater. It is to add here that in the recent years, several ecological changes have taken place in this ecosystem as a result of man-made interferences such as deforestation, reclamation, dredging operation and release of pollutants. The deforestation has not only resulted in heavy siltation and accretion of sand into the estuary which has affected the mean depth and tidal prism in the estuary, but also has impact on the failure and irregularity in the seasonal rainfall. Other activities like release of pollutants from industries and overuse of pesticides and fertilizers in agriculture and subsequent land drainage during monsoon have serious impact on the ecosystem. Such man-made ecological changes stress the necessity for detailed investigations to assess the biological resources at primary, secondary and tertiary trophic levels in relation to the environmental characteristics of the ecosystem to have up-to-date information on the potential resources.

While studying the seasonal fluctuation of phytoplankton and primary production in the estuarine waters, what is needed is to estimate simultaneously the related environmental parameters from the same watermass prevailing in the same space and time, since these environmental factors show variations from place to place and time to time by diurnal and day-to-day changes as a result of the watermasses being constantly renewed by the inflow of fresh water from the rivers and sea water from the adjoining sea and by the local mixing processes occurring in the estuarine ecosystem.

With reference to phytoplankton pigments and primary productivity of Cochin backwater, such collective information available in the literature is meagre especially in the last fifteen years (1976-90) and particularly during the southwest monsoon season. The Ernakulam channel in the Cochin backwater forms the main source of estuarine waters to feed several hectares of potential aquaculture sites along the south during high tide and to enrich the neighbouring marine environment during low tide.

In view of the above facts, this dissertation presents the results of investigations carried out in the Ernakulam channel of Cochin backwater extending between the barmouth and the railway cum road bridge (in the south) on the distribution and abundance of phytoplankton pigments (Chlorophyll 'a', 'b', 'c', carotenoids and phaeo-pigments) and primary productivity in relation to the environmental parameters (rainfall, light, temperature, salinity, dissolved oxygen, phosphate, nitrate, nitrite, tide and time) during the southwest monsoon months from June to September 1990.

M A T E R I A L A N D M E T H O D S

Description of the backwater environment

The Cochin backwater system having the Vembanad Lake in the South and comprising an area of 300 sq.km extends from Alleppey in the south to Azhikode in the north between Lat. 09°32' - 10°12'N and Long. 76°10' - 76°29'E. It is the largest estuarine system of its kind on the west coast of India having permanent sea connection at Cochin and Azhikode. The Cochin backwater is subjected to strong tidal influence from the sea and mixing of freshwater from the river systems in the south and north, thus providing estuarine condition, with higher salinity gradient towards the vicinity of barmouth. During southwest monsoon season, almost fresh water condition persists throughout the estuary at the surface with saline condition at the bottom where the depth is considerable. It is deeper in the harbour area reaching the maximum of 12 m and shallower in the upper reaches and along the sides with the depth range of 1-5 m. The southern sector of the backwater in the Cochin region is divided into 'Mattancherry channel' and 'Ernakulam channel' and separated by Willingdon island. The Ernakulam channel, thus constituting a part of the Cochin backwater, lies adjacent to the mainland of Cochin city.

Preliminary Survey

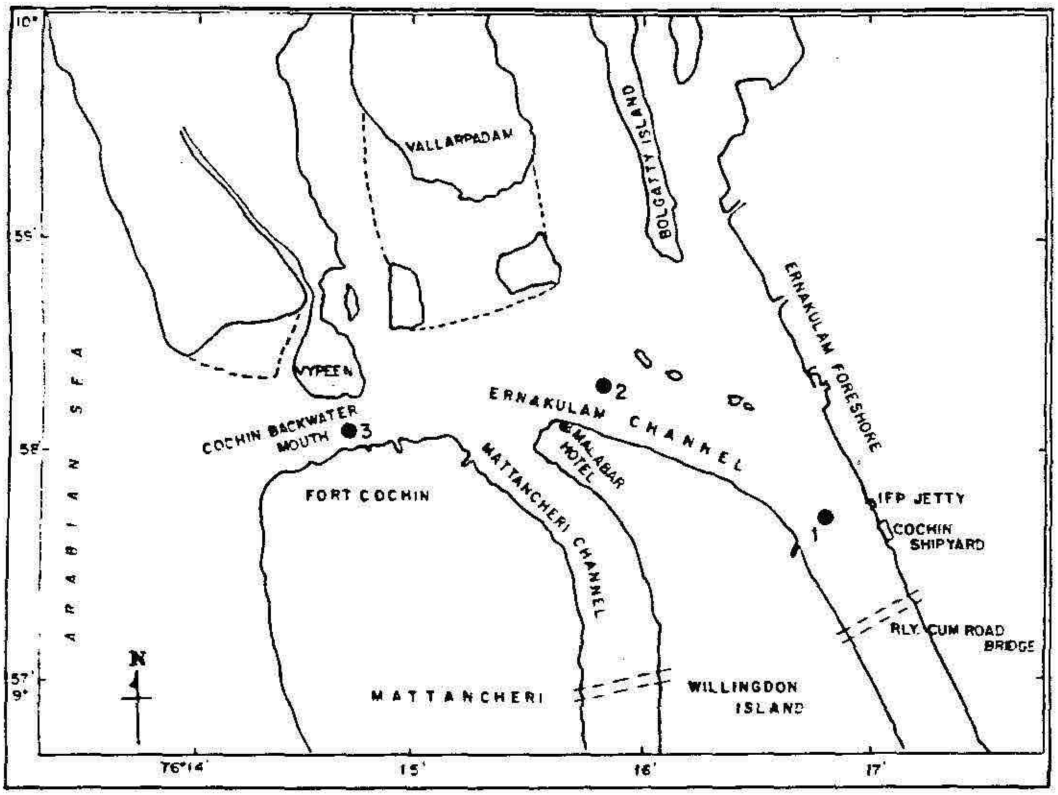
Prior to the commencement of the work, a preliminary survey was conducted in the backwater adjacent to the mainland of Cochin city during the second fortnight of May 1990 to fix up the sampling stations and the time of collection for regular weekly sampling. For this purpose, water samples were collected from different areas at different hours of the day, taking into account the differences due to high and low tides and analysed. Based on the results obtained, these stations were carefully selected in the study area at almost equal distance from each other so as to be representative of the respective zones; and to keep uniformity, the time of sampling was fixed as 0830-0930 hrs. The actual depths of stations were noted and euphotic depths were confirmed for these stations by Secchi disc reading and primary productivity experiments.

Study area

The present study was confined to the Ernakulam channel in the Cochin backwater extending between the railway cum road bridge (in the south) and Cochin barmouth. To facilitate programming and collection of data, the study area was divided into three functional units viz. (1) South Zone, (2) Middle Zone, and (3) Barmouth Zone (Fig. 1).

Station 1: Opposite to Shipyard in the 'South Zone'; depth of station varied between 5-6 m, while the mean euphotic depth was 1.25 m only. The area was influenced by

Fig. 1. MAP SHOWING SAMPLING STATIONS



relatively more of fresh water influx than by tidal current during monsoon season.

Station 2: Opposite to Malabar Hotel near the northern terminus of Willingdon island in the 'Middle Zone'; depth varied between 7-8 m, while the mean euphotic depth was 1.5 m; and the area was influenced both by moderate flood flow at surface and tidal current at the bottom during monsoon season.

Station 3: Opposite to 'Aspinwall' between northern terminus of Fort Cochin and southern terminus of Vypeen in the 'Barmouth Zone'; depth of station varied between 9-10 m; while the mean euphotic depth was 1.75 m only and the area was influenced relatively more by the flood current at surface during low tide and tidal current at the bottom during high and low tides in the monsoon season.

Collection of field data

Weekly sampling was made regularly from these three fixed stations (on the same day) at surface and bottom from the first week of June to last week of September 1990 at the prescribed time between 0830 and 0930 hrs., availing the facilities of R.V. Cadalmin-IX of the Central Marine Fisheries Research Institute at Cochin. Apart from the regular collections, one diurnal observation was also carried out at station 3 during July from 0630 to 1830 hrs; and sampling was made from surface and bottom at bihourly interval, while tidal height was recorded at every hour.

Environmental data on rainfall, tide level, light penetration, water temperature and water samples for dissolved oxygen and salinity were collected from the surface and bottom and nutrients from the surface, mid-depth and bottom to study their relationship with phytoplankton production. Surface water temperature was measured at the site soon after collection of water sample with an accuracy of $\pm$ 0.1°C using Precision mercury thermometer (0-50°C) and bottom temperature through the reversing thermometer fitted in the Nansen's bottle. Water samples for dissolved oxygen collected in 125 ml narrow mouthed bottles were fixed on the spot by Winkler 'A' and 'B'. Water samples for salinity and nutrients were collected together in narrow mouthed air tight plastic bottles of 500 ml capacity and transported in an ice box to C.M.F.R.I. laboratory for analysis.

For the qualitative estimation of phytoplankton groups, plankton samples were collected from the surface waters by filtering 10 litres of water through the bolting silk No. 25 (mesh size 60 µm) and the samples were preserved in 5% diluted formalin. Since the cell count was found very much variable in the preliminary survey irrespective of tides, space and time, phytoplankton production was quantitatively estimated by the determination of chlorophyll pigments and primary productivity.

For the quantitative estimation of chlorophyll, carotenoid and phaeo-pigments, water samples from the surface, mid-depth and near-bottom were collected at the three fixed stations in plastic bottles of 500 ml capacity each and transported to the C.M.F.R.I. laboratory for analysis and estimation.

To estimate primary productivity, light and dark bottle (oxygen estimation) method was adopted. Since the euphotic depth varied between 1 and 2 m only among the three stations, water samples were collected from the surface only for regular primary productivity experiments; and to keep uniformity, three hours of incubation were given every time for the light and dark bottles under simulated in situ condition in the field; while the initial bottle was fixed on the spot by Winkler 'A' and 'B' as in the case of Oxygen estimation. The samples thus fixed (initial, dark and light bottles) for the three stations were transported carefully to the laboratory for further analysis and estimation. For diurnal experiments, water samples from surface and near-bottom were used.

Laboratory analysis

Water samples brought from the field were analysed as far as possible on the same day for hydrological properties. Determination of salinity, dissolved oxygen and nutrients such as phosphate, nitrite and nitrate were made according to the methods prescribed by Strickland and Parsons (1968).

Salinity was estimated by Mohr-Knudsen method as described by Strickland and Parsons (1968).

Dissolved oxygen was estimated by Winkler method.

Reactive phosphate estimation was made by the method of Murphy and Riley (1962) where the extinction was measured in Spectrophotometer at 885 nm.

Nitrite was estimated by Bendschneider and Robinson method (1952) and the absorbance was measured at 543 nm.

Nitrate was estimated by the method of Morris and Riley as described in Strickland and Parsons (1968). This method is based on the reduction of nitrate to nitrite and its subsequent photometric measurement at 543 nm; and the nitrite-N value estimated earlier is deducted from this value to get the actual nitrate-N. From the O.D. values obtained for phosphate, nitrite and nitrate samples, their concentration in µg at/l were derived from the respective standard graphs prepared using FAO standards. The same spectrophotometer was used throughout the study for the measurement of O.D.

Phytoplankton groups: From the plankton samples collected, major groups of phytoplankters were identified for their relative abundance using Sedwick-Rafter cell under microscope.

Phytoplankton pigments: Chlorophyll 'a', 'b', 'c' and carotenoids were estimated according to the methods prescribed by Parsons *et al.* (1984). Phytoplankton pigments in an aliquot of 500 ml of water sample were separated by filtering through Whatman GF/C glass fibre filter (47 mm). While filtering the sample, a few drops of suspension of magnesium carbonate in distilled water was added to prevent acidity on the filter. The filter was then extracted with 10 ml of 90% acetone and kept in small air-tight screw-cap bottles inside the refrigerator for 20-24 hours. Later, the absorbance of the clear acetone extract was measured photometrically as against 90% of acetone (as blank) at different wave lengths of 750, 664, 647, 630, 510 and 480 nm and the concentration of chlorophylls 'a', 'b', 'c' and carotenoids were calculated using the equations given by Parsons et al. (1984).

C_a= Chlorophyll 'a' = $11.85\ E_{664} - 1.54\ E_{647} - 0.08\ E_{630}$

C_b= Chlorophyll 'b' = $21.03\ E_{647} - 5.43\ E_{664} - 2.66\ E_{630}$

C_c= Chlorophyll 'c' = $24.52\ E_{630} - 1.67\ E_{664} - 7.60\ E_{647}$

C_p= Plant carotenoids = $7.6\ (E_{480} - 1.49\ E_{510})$

where E is the absorbance at the respective wave lengths. Each extinction were corrected for a small turbidity blank by substracting the 750 nm reading from 664, 647 and 630 nm absorptions. The 510 nm absorbance was corrected by substracting 2 x 750 nm absorbance and the 480 nm absorbance was corrected by substracting 3 x 750 nm absorbance. Then the chlorophylls and carotenoids were estimated in mg/m^3 using the formula $\frac{c \times v}{V \times l}$ where Ca, Cb and Cc are the three chlorophylls substituted for C in the above equation; v = volume of acetone in ml; V = volume of water sample in litre; and l = the pathlength of cuvette in cm.

For plant carotenoids, Cp value is substituted for C in the same equation as is used for chlorophylls.

For the estimation of phaeo-pigments, the procedure is similar to that of chlorophylls as given above. The extinction of the extract was measured at 665 and 750 nm. To the cuvette, 2 drops of dilute HCl was added (10 ml conc. HCl in 100 ml distilled water) and then remeasured the extinction at 665 and 750 nm. Each 750 nm reading is substracted from the corresponding 665 nm extinction and phaeo-pigment concentration was calculated using the following equation:

$$\text{Phaeo-pigment } (mg/m^3) = \frac{26.7\ (1.7(665_a) - (665_o)\ X\ v}{V \times 1}$$

where 665_o = extinction at 665 nm before acidification

665_a = extinction at 665 nm after acidification

v = volume of acetone extract (ml)

V = volume of water filtered (litres)

1 = path length of the cuvette (cm)

The same spectrophotometer was used till the end of the present investigation.

Primary productivity: Measurements on primary productivity were made using Gaarder and Gran's (1927) light and dark bottle method as described by Strickland and Parsons (1968). The dissolved oxygen values for the initial, dark and light bottles were determined by Winkler method. The difference in oxygen concentration (ml/l) between the light and dark bottles was converted into its carbon equivalent (mg C/l) for gross production and the difference between the light and initial values was converted into carbon equivalent for net production

(1 ml O_2 = 0.536 mg C) using the PQ of 1.25; and the surface production was estimated per m^3 of water per day. (The mean photosynthetic time was considered as 10 hours per day).

In the present investigation the column productivity was estimated from the simulated in situ experiments by multiplying the surface value with the euphotic depth (m) rather than by the actual depth as suggested by Steeman Nielsen and Aabye Jensen (1957) for the shallow estuarine waters.

Treatment of data

Since the measurements were subjected to diurnal, microdistributional and experimental sources of variability, care was taken in the processing of data; and as far as possible individual values were not considered for the results and discussion. Taking tidal variations into account, the data collected at the lowest tide as well as highest tide during the regular weekly survey were eliminated and as far as possible the data collected close to mid water level irrespective of high or low tide were considered while processing the data for the present investigation. The weekly/fortnightly data thus obtained were averaged for station-wise fortnightly mean values. From the fortnightly mean values, monthly mean values were calculated for the three stations to study the month-wise variation and abundance in phytoplankton pigments and primary productivity in relation to rainfall and hydrographic parameters. The monthly mean thus obtained for the different parameters were consolidated respectively to get the season's average for the three zones. The values thus obtained for the three zones were pooled together to get an average picture of the study area (Ernakulam channel) for the different parameters during the southwest monsoon season.

The monthly and seasonal data thus obtained during June-September 1990 were used to study the inter-relationship between phytoplankton pigments and primary productivity and for correlating the abundance of phytoplankton pigments and primary productivity with the environmental parameters.

The qualitative data obtained on the major phytoplankton groups were represented in percentage composition to study their relative abundance and fluctuations in different months and for the season; and to examine their relationship with the phytoplankton pigments.

The bihourly diurnal data collected on phytoplankton pigments and primary productivity were used to correlate their abundance in relation to tide and time.

Statistical analysis

Statistical analysis was done to examine the influence of various hydrological parameters on productivity parameters. For this a multiple regression relationship was set up with all the parameters using a computer. The hydrological factors such as temperature, salinity, dissolved oxygen and nutrients such as phosphate, nitrate and nitrite and productivity indices like total chlorophylls (a+b+c), phaeo-pigments and carotenoids were reckoned as the independent variables and gross primary production as the dependent variable. Data pertaining to the three stations were pooled together to get the correlation and regression coefficients for the study area (Ernakulam channel). Statistical analysis was done for the surface water and euphotic column separately.

The general conclusions made in this dissertation were based on specific observations derived from the zone-wise analysis and from the practical knowledge gained in the field.

R E S U L T S

1. THE ENVIRONMENT

The physical and chemical properties exert considerable influence on the distribution and abundance of fauna and flora in the estuarine environment. In the main channel of the Cochin backwater where the investigation was carried out, the depth varied from 5-6 m at station 1, 7-8 m at station 2 and 9-10 m at station 3 with variations in tides and flood flow; while along the side of the channel, the depth varied from 1-5 m. Tidal amplitude recorded during the diurnal observation at station 3 in July was 45 cm only.

Water was turbid at all stations throughout the course of this investigation. Light penetration did not show much variation from station to station and the Secchi disc reading varied from 40-60 cm among the stations attaining a mean value of 50 cm in the study area during June-September. Accordingly, the mean euphotic depth determined for the three stations were 125, 150 and 175 cm respectively; and the average euphotic depth in the study area was 150 cm during the period of investigation.

The monthly and season's consolidated data obtained for the three stations in the present investigation on rainfall, water temperature, salinity and dissolved oxygen from the surface and bottom water during the southwest monsoon (June-September 1990) are presented in Table 1 and of reactive phosphate, nitrate and nitrite in Table 2. Fortnightly and monthly variations and abundance in their values (Station-wise and for the study area as a whole) in surface waters are given in Figs. 2-5 and 6-9 respectively. The column average (entire water column) of temperature, salinity and dissolved oxygen and the estimated total column production of nutrients are given station-wise and for the study area (average of stations 1-3) in Figs. 10-13 & 14-17 for their fortnightly and monthly distribution respectively. Table 3 gives the monthly averages of nutrients for the 3 stations (zones) in the euphotic column and Table 4 for the entire study area (average of 3 stations) in the euphotic column and the water column below the euphotic zone.

1.1. Rainfall

The Cochin backwater had local rainfall of 1900 mm during the southwest monsoon in 1990, with intermittent peaks during the second fortnight of May and first fortnight of July. The fortnightly rainfall data recorded from May to September were 66, 494, 228, 170, 484, 197, 126, 60, 45 and 30 mm in the order, while the monthly values were 560, 398, 681, 186 and 75 mm for the respective months with peak in July. The rainfall for June-July and August-September were 1079 and 261 mm respectively.

1.2. Temperature

Water temperature at surface and bottom ranged from 27.6-28.9°C and 24.3-28.1°C with mean values of 28.05 and

26.50°C respectively showing vertical stratification in the estuary during June-September. At the bottom, temperature ranged from 27.4-28.1°C in June-July and 24.3-25.95°C in August-September with their mean values as 27.6°C and 25.3°C respectively, while it was 28.4 and 27.9°C at surface correspondingly in the study area. During the second half of the season (August-September), the range in bottom values were 25.4-25.9, 24.30-25.95 and 24.5-25.8°C at stations 1-3 respectively. Station-wise mean values for the season showed that temperature at surface and bottom were relatively higher at station 1; and in general, low values were recorded in August (Table 1). The overall column average in the study area was 27.25°C.

1.3. Salinity

Salinity at surface and bottom ranged from 0.54-15.44‰ and 0.91-29.82‰ with the mean of 4.79 and 15.38‰ respectively showing vertical stratification in the estuary. During June-July the average value at the bottom was as low as 5.39‰ while it was 25.37‰ in August-September; when the mean salinity values at the surface were 1.31 and 8.23‰ respectively. During August-September, the station-wise range in bottom values were 21.64-22.01, 28.25-29.82 and 22.47-28.03‰ for the three stations respectively. In general, very low values were recorded in July at surface and bottom, disrupting the vertical stratification, corresponding to the peak rainfall recorded in July (Table 1). The overall average for the water column was 10.08‰ during June-September.

Table - 1

Distribution of temperature, salinity and dissolved oxygen in the Ernakulam Channel of Cochin backwater

Month	R.F. (mm)	Stn. No.	Temperature (°C)		Salinity (‰)		Dissolved Oxygen (ml/l)	
			Surface	Bottom	Surface	Bottom	Surface	Bottom
June	398	1	28.50	28.10*	1.15	6.92	3.67	3.37
		2	28.72	27.65	1.75	11.17	3.71	3.05
		3	28.67	27.67	2.21	9.61	3.72	3.00
July	681	1	28.87*	27.43	0.54*	0.91*	3.97	3.78
		2	27.92	27.40	1.09	1.31	3.72	3.88
		3	27.82	27.40	1.14	2.40	4.06*	3.94*
August	186	1	27.82	25.43	4.68	22.01	3.91	2.72
		2	27.67	24.30*	5.89	29.82*	3.98	2.28
		3	27.65	25.83	6.68	22.47	3.98	3.30
September	75	1	28.57	25.90	8.01	21.64	4.04	2.41
		2	27.87	25.95	8.71	28.25	3.26*	2.20*
		3	27.60*	24.53	15.44*	28.03	3.28	2.34
June-September	1340	1	28.19	26.70	3.59	12.87	3.90	3.07
		2	28.04	26.31	4.36	17.64	3.67	2.85
		3	27.93	26.36	6.43	15.63	3.76	3.15
Average for the study area			28.05	26.50	4.79	15.38	3.77	3.02
			27.25		10.08		3.40	

* Minimum and maximum values

1.4. Dissolved oxygen

At surface, dissolved oxygen values ranged from 3.26-4.06 with mean value of 3.77 ml/l while the bottom range and mean were 2.20-3.94 and 3.02 ml/l respectively (Table 1). Relatively low values were recorded at the bottom in August-September (mean 2.54 ml/l) than in June-July (mean 3.50 ml/l) when the surface averages were 3.74 and 3.81 ml/l respectively, indicating that surface values did not show any remarkable variation during this season. Among the stations, relatively higher values were recorded at station 1. The overall average for the water column was 3.40 ml/l.

1.5. Reactive Phosphate

At surface, phosphate-P values ranged from 2.45-12.35 with a mean of 6.30 µg at/l and at bottom the range and mean were 0.96-5.15 and 2.60 µg at/l respectively (Table 2). During the first half of the season (June-July) the mean values were estimated as 8.56 and 3.65 µg at/l at surface and bottom, while in the second half (August-September) they were 4.03 and 1.54 µg at/l respectively.

In the entire water column of the study area (mean depth 7.5 m) the estimated phosphate concentration varied from 15.29 (September) to 53.69 mg at/m^2 in July (µg at/l = mg at/m^3) whereas in the euphotic column (mean depth 1.5 m), it ranged from 4.77 in September to 12.84 mg at/m^2 in June and July. The averages for the first half (June-July) and the second half of

Table - 2

Distribution of inorganic phosphate, nitrate and nitrite in the Ernakulam Channel (mean values in μg at/l)

Month	Stn. No.	PO_4-P Surface	PO_4-P Bottom	NO_3-N Surface	NO_3-N Bottom	NO_2-N Surface	NO_2-N Bottom
June	1	12.35*	4.31	17.70*	6.04	3.45*	1.49*
	2	6.22	2.64	16.75	6.30	1.89	0.56
	3	7.12	1.86	14.90	6.65*	1.32	0.45
July	1	10.67	4.33	13.37	4.62	1.02	0.41
	2	5.12	3.65	13.55	3.98	0.94	0.62
	3	9.90	5.15*	10.25	5.35	1.83	0.73
August	1	8.05	2.46	6.62	2.93	1.34	0.39
	2	3.42	1.18	7.75	0.53	0.95	0.41
	3	3.20	2.25	4.9	0.80	0.58*	0.38
September	1	3.12	1.34	4.53	1.41	0.73	0.30*
	2	2.45*	0.96*	1.76	0.87	1.27	0.44
	3	3.97	1.03	1.63*	0.63*	0.67	0.34
June-September	1	3.55	3.11	10.55	3.75	1.63	0.65
	2	4.30	2.11	9.95	2.92	1.26	0.51
	3	6.05	2.57	7.92	3.36	1.10	0.47
Average for the study area		6.30	2.60	9.47	3.34	1.33	0.54
		4.45		6.41		0.94	

*Minimum and maximum values

Table - 3

Stationwise monthly mean values of nutrients in the euphotic column (mg at/m^2)

Nutrients	Stn. No.	June	July	August	September
	1	15.43	13.33	10.06	3.91
PO_4-P	2	9.33	7.68	5.13	3.67
	3	12.46	17.32	5.60	6.94
	1	22.12	16.17	8.27	5.66
NO_3-N	2	25.12	20.32	11.62	2.64
	3	26.07	17.93	8.57	2.85
	1	4.31	1.27	1.67	0.91
NO_2-N	2	2.83	1.41	1.42	1.90
	3	2.31	3.20	1.01	1.17

the season (August-September) in the euphotic column of the study area were 12.84 and 6.05 mg at/m^2 respectively (Table 4).

In general, the distribution showed a decreasing trend at surface and water column from June to September with very high values during June-July (Figs. 6-9 and 14-17). Among the three zones, South zone recorded the highest values at surface and bottom (Table 2).

1.6. Nitrate

At surface, nitrate-N values ranged from 1.63-17.7 with the mean value of 9.47 μg at/l while at bottom the values ranged from 0.63-6.65 with mean of 3.34 μg at/l. During the first half of the season (June-July), mean values for the surface and bottom were 14.42 and 5.49 μg at/l while in the second half (August-September) they were 4.53 and 1.19 μg at/l respectively.

In the entire water column, the estimated nitrate-N concentration varied from 12.92 (September) to 83.48 mg at/m^2 (June); and in the euphotic column it varied from 3.96 (September) to 24.69 mg at/m^2 (June); the averages for June-July and August-September in the euphotic column for the study area were 21.58 and 6.79 mg at/m^2 respectively (Table 4).

TABLE - 4

Estimated nutrients in the euphotic and below euphotic water columns in the study area (mean values of stations 1-3 expressed in mg at per m^2 of water)

Nutrients	Euphotic column		Below euphotic column	
	June-July	August-September	June-July	August-September
PO_4-P	12.84	6.05	31.32	14.98
NO_3-N	21.58	6.79	52.13	13.22
NO_2-N	2.61	1.38	6.33	3.52

The surface and column values showed a decreasing trend from June to September with very high values during the first half of the season (June-July) and among the three stations highest values were recorded at station 1 (south zone).

1.7. Nitrite

At surface NO_2-N values ranged from 0.58-3.45 with the mean value of 1.33 μg at/l while at bottom the values ranged from 0.30-1.49 with the mean value of 0.54 μg at/l (Table 2). During the first half of the season (June-July) the mean values for the surface and bottom were 1.74 and 0.71 μg at/l while in the second half (August-September) they were 0.92 and 0.38 μg at/l respectively, indicating higher values during peak monsoon season.

In the entire water column, the estimated nitrite-N concentration varied from 4.6 (August) to 10.41 mg at/m^2 (June); and in the euphotic column it varied between 1.33 (September) and 3.33 mg at/m^2 (June). The averages for June-July and August-September in the euphotic column of the study area were 2.61 and 1.38 mg at/m^2 respectively (Table 4). A decreasing trend from June-September was noted in the mean column values and it was not significant in the surface waters.

The estimates of phosphate, nitrate and nitrite for the water column below the euphotic zone (per m^2) showed higher values than that of euphotic zone, since the column depth below euphotic zone was more than the euphotic depth (Table 4).

2. PHYTOPLANKTON

The dominant groups of phytoplankters found in the surface waters during the season were diatoms like Coscinodiscus, Nitzschia, Skeletonema, Chaetoceros, Fragilaria, Rhizosolenia, Navicula, Pleurosigma and Biddulphia; and dinoflagellates like Ceratium and Peridinium. Others were mainly freshwater forms since the backwater was diluted considerably by fresh water. This included forms like Oscillatoria, Oedogonia, Spirogyra, Scenedesmus, Volvox etc. Other phytoplankters recorded in the collections were Asterionella, Bacteriastrum, Cerataulina, Thalassiothrix, Planktoniella etc. The most dominant diatom recorded througnout the season was Coscinodiscus.

3. PHYTOPLANKTON PIGMENTS

Fortnightly distribution pattern and abundance of phytoplankton pigments (chlorophyll a, b & c, carotenoids and phaeo-pigments) in surface waters for the 3 stations are given in Figs. 2-4 and for the study area (average of 3 stations) are given in Fig. 5; and their monthly distribution and abundance are given in Figs. 6-8 and 9 respectively and in Table 5.

Fortnightly distribution pattern and abundance of phytoplankton pigments in the entire water column for the 3 stations are given in Figs. 10-12 and for the study area (average of 3 stations) in Fig. 13 and their monthly distribution and abundance are given in Figs. 14-16 and 17 respectively. The euphotic column production values (monthly averages) for the 3 stations are given in Tables 6-8 and for the study area as a whole in Table 9. The distribution of pigments in the euphotic and below euphotic columns of water in the study area as a whole are given in Table 10.

3.1. <u>Chlorophyll 'a'</u>

In the surface waters, the concentration of chlorophyll 'a' ranged from 5.19 (July, at station 2) to 26.63 mg/m^3 (September, at station 2) (Table 5). During June-July and August-September the average concentrations were 6.75 and 17.51 mg/m^3 respecti[illegible] showed that the variations among stations were not prominent. However, values were relatively more at station 3 (Table 5). The overall average for the season was 12.13 mg/m^3.

Table - 5

Distribution of phytoplankton pigments in the surface waters
(Values in mg/m^3)

Month	Stn. No.	Chl.'a'	Chl.'b'	Chl.'c'	Tot.Chls. (a+b+c)	Carote-noids	Phaeo-pigments
June	1	7.16	4.81	2.62	14.69	3.28	5.10
	2	6.59	2.26	4.66	13.52	0.20*	4.74
	3	6.74	2.26	3.79	12.79*	1.59	3.27*
July	1	7.34	2.52	4.61	14.48	1.63	7.04
	2	5.19*	3.37	6.37	14.93	1.67	3.92
	3	7.43	5.60	2.30	13.94	0.31	3.47
August	1	11.90	8.12*	1.39*	21.40	5.19	9.33
	2	10.77	1.56*	6.15	18.49	4.58	6.41
	3	10.72	1.94	5.30	17.96	1.79	5.87
September	1	18.76	2.93	4.17	25.86	6.01	6.28
	2	26.63*	1.96	6.49*	35.08	7.92	12.27*
	3	26.35	2.84	6.07	35.13*	8.78*	11.67
June-September	1	11.29	4.59	3.19	19.11	4.03	7.07
	2	12.29	2.29	5.92	20.50	3.59	6.77
	3	12.82	3.16	4.36	19.95	3.27	7.32
Average for the study area		12.13	3.35	4.49	19.85	3.63	7.05

*Minimum and maximum values

Table - 6

Phytoplankton pigments in the euphotic column at station-1

Parameters	June	July	August	September
Chlorophyll 'a'(mg/m^2)	8.95	9.17	14.87	23.45
Chlorophyll 'b'(")	6.01	3.15	10.15	3.66
Chlorophyll 'c'(")	3.27	5.76	1.74	5.21
Total Chlorophylls (a+b+c) (")	18.23	18.08	26.76	32.32
Carotenoids (")	4.10	2.04	6.49	7.52
Phaeo-pigments (")	6.37	8.80	12.35	7.85

Table - 7

Phytoplankton pigments in the euphotic column at station-2

Parameters		June	July	August	September
Chlorophyll 'a'	(mg/m^2)	9.88	7.78	16.15	39.94
Chlorophyll 'b'	(")	3.39	5.05	2.34	2.94
Chlorophyll 'c'	(")	6.99	9.56	9.22	9.73
Total Chlorophylls (a+b+c)	(")	20.26	22.39	27.71	52.61
Carotenoids	(")	0.30	2.50	6.87	11.38
Phaeo-pigments	(")	7.11	5.88	9.61	18.40

Table - 8

Phytoplankton pigments in the euphotic column at station-3

Parameters		June	July	August	September
Chlorophyll 'a'	(mg/m^2)	11.79	13.09	18.76	46.11
Chlorophyll 'b'	(")	3.95	9.30	3.39	4.97
Chlorophyll 'c'	(")	6.63	4.02	9.27	10.62
Total chlorophylls (a+b+c)	(")	22.37	26.91	31.42	61.70
Carotenoids	(")	2.78	0.54	10.27	15.36
Phaeo-pigments	(")	5.72	14.82	3.13	20.42

In the entire water column (mean depth 7.5 m) the estimated chlorophyll 'a' concentration varied from 19.75 (July) to 82.5 mg/m^2 (September) whereas in the euphotic zone the values varied from 10.00 to 35.86 mg/m^2 in the respective months (Table 9). The averages for the first half (June-July) and second half of the season (August-September) in the euphotic column of the study area were 10.12 and 26.27 mg/m^2 respectively (Table 10). In general the distribution pattern showed an increasing trend from June to September at surface and in the water column.

3.2. Chlorophyll 'b'

In the surface waters, concentration of chlorophyll 'b' ranged from 1.56-8.12 mg/m^3 at stations 2 and 1 in August (Table 5). During June-July and August-September the average values were 3.49 and 3.35 mg/m^3 respectively. Relatively higher concentrations were recorded at station 1. The overall average for the season was 3.35 mg/m^3.

In the entire water column the estimated chlorophyll 'b' concentration varied from 6.67 (June) to 13.53 mg/m^2 (September) whereas in the euphotic zone values varied from 3.85 (September) to 5.83 mg/m^2 (July). The averages for June-July and August-September in the euphotic column of the study area were 5.24 and 4.82 mg/m^2 respectively (Table 10). Relatively low values were observed in September and higher values in July and August in the euphotic zone, while the concentration was higher in the water column below the euphotic depth in September.

Table - 9

Phytoplankton pigments in the euphotic column of study area (average of stations 1-3)

Parameters		June	July	August	September
Chlorophyll 'a'	(mg/m^2)	10.24	10.00	16.69	35.36
Chlorophyll 'b'	(")	4.66	5.83	5.80	3.85
Chlorophyll 'c'	(")	5.53	6.63	6.42	3.29
Total Chlorophylls (a+b+c)	(")	20.43	22.46	28.91	43.00
Carotenoids	(")	2.53	1.38	5.77	11.35
Phaeo-pigments	(")	6.55	7.63	7.08	15.10

Table - 10

Distribution of phytoplankton pigments in the euphotic and below euphotic water columns in the study area (mean values of stations 1-3)

Parameters	Euphotic column		Below euphotic column	
	Jun-Jul	Aug-Sep	Jun-Jul	Aug-Sep
Chlorophyll 'a' (mg/m^2)	10.12	26.27	12.09	33.27
Chlorophyll 'b' (")	5.24	4.82	1.80	7.99
Chlorophyll 'c' (")	6.08	7.35	4.87	6.31
Carotenoids (")	1.95	8.56	3.58	12.15
Total chlorophylls (a+b+c) (")	21.44	38.45	18.82	47.41
Phaeo-pigments (")	7.09	11.09	12.38	25.50

3.3. Chlorophyll 'c'

In the surface waters concentrations of chlorophyll 'c' ranged from 1.39 (August, Station 1) to 6.49 mg/m^3 (September, Station 2) (Table 5). During June-July and August-September the average concentrations were 4.05 and 4.90 mg/m^3 respectively. Relatively high concentrations were recorded at station 2 and the overall average for the season was 4.49 mg/m^3.

In the entire water column the estimated chlorophyll 'c' concentration varied from 10.1 (June) to 16.94 mg/m^2 (August) whereas in the euphotic zone values varied from 5.53 (June) to 8.29 mg/m^2 (September). The averages for June-July and August-September in the euphotic column of the study area were 6.08 and 7.35 mg/m^2 respectively (Table 10).

3.4. Total chlorophylls (a+b+c)

In the surface waters concentration of total chlorophylls ranged from 12.79 (June, Station 3) to 35.13 mg/m^3 (September, Station 3) (Table 5). During June-July and August-September the average concentrations were 14.29 and 25.63 mg/m^3 respectively. Relatively higher concentration was recorded at station 2 and the overall average for the season was 19.85 mg/m^3.

In the entire water column the estimated concentration of total chlorophylls varied from 38.98 (July) to 106.5 mg/m^2 (September), whereas in the euphotic zone values varied from 20.43 (June) to 48.0 mg/m^2 (September). The averages for June-July and August-September in the euphotic column of the study area were 21.44 and 38.45 mg/m^2 respectively (Table 10). Very high concentrations of total chlorophylls were recorded in the surface as well as in the euphotic zone during the 2nd half and a secondary mode was observed in all the stations during first half of the season. A progressive increase in the concentration was observed in surface and column production from June-September.

3.5. Carotenoids

In the surface waters concentration of carotenoids ranged from 0.20 (June, Station 2) to 8.78 mg/m^3 (September, Station 3) (Table 5). During June-July and August-September the average concentrations were 1.30 and 5.71 mg/m^3 respectively. Among the stations, concentrations were relatively more at station 1. The overall average for the season in the study area was 3.63 mg/m^3.

In the entire water column the estimated carotenoid concentration varied from 5.4 (June) to 21.67 mg/m^2 (September) whereas in euphotic zone values varied from 1.38 (July) to 11.35 mg/m^2 (September). The averages for June-July and August-September in the euphotic column of the study area were 1.95 and 8.56 mg/m^2 respectively (Table 10). Column production in general showed an increasing trend from June-September.

3.6. Phaeo-pigments

In the surface waters concentrations of phaeo-pigments ranged from 3.27 (June, Station 3) to 12.27 mg/m^3 (September, Station 2) (Table 5). During June-July and August-September the average concentrations were 5.42 and 8.73 mg/m^3 respectively. Among the stations concentrations were relatively more at station 3, followed by at station 1. The overall average for the season in the study area was 7.05 mg/m^3 (Table 5).

In the entire water column the estimated phaeo-pigment concentration varied from 17.55 (June) to 44.11 mg/m^2 (September) whereas in euphotic zone values varied from 6.55 (June) to 15.10 mg/m^2 (September) (Table 9). The averages for June-July and August-September in the euphotic column of the study area were 7.09 and 11.09 mg/m^2 respectively (Table 10). A progressive increase in the concentration was observed in the surface and water column from June-September with very high values recorded during August-September.

4. PRIMARY PRODUCTIVITY

Fortnightly and monthly variations in primary productivity for the stations and the study area as a whole (average of 3 stations) for the surface and water column are presented in Figs. 2-9 and 10-17 respectively; and station-wise monthly mean values of column production are given in Table 11.

4.1. Gross primary production

In the surface waters gross production varied from 0.241 (June, Station 3) to 2.55 g C/m^3/day (September, Station 2). During June-July and August-September the average gross values were 0.396 and 1.45 g C/m^3/day respectively. Among the stations high values of gross production were recorded at station 2. The overall average for the season was 0.960 g C/m^3/day.

In the euphotic column gross production ranged from 0.447 (June, Station 1) to 3.25 g C/m^2/day (September, Station 3) (Table 11). The average values for June-July and August-September were 0.669 and 2.029 g C/m^2/day (Table 15). Among stations high values were recorded at station 3. The overall average for the season was 1.349 g C/m^2/day.

4.2. Net primary production

The net production varied from 0.111 (June, Station 3) to 2.3 g C/m^3/day (September, Station 2). During June-July and August-September the average net values were 0.230 and 1.09 g C/m^3/day respectively. Among the stations high values of net production were recorded at station 2. The overall average for the season was 0.668 g C/m^3/day constituting 69.6% of gross production.

The net production in the euphotic column ranged from 0.201 (June, Station 3) to 1.857 g C/m^2/day (September, Station 2). The average values for June-July and August-September were 0.439 and 1.191 g C/m^2/day respectively

Table - 11

Station-wise monthly mean values of primary productivity in the euphotic column

Primary productivity	Stn.No.	June	July	August	September
	1	0.447	0.690	1.014	1.347
Gross Production ($g\ C/m^2/day$)	2	0.936	0.530	1.378	3.196
	3	0.801	0.613	2.039	3.247
	Average	0.728	0.611	1.476	2.582
	1	0.201	0.407	0.527	0.857
Net Production ($g\ C/m^2/day$)	2	0.651	0.502	0.607	1.857
	3	0.571	0.303	1.505	1.792
	Average	0.474	0.404	0.880	1.502

(Table 15). Among the stations high values were recorded at station 3. The overall average for the season was 0.815 g C/m^2/day which constituted 60.4% of the gross production. In general, primary productivity also showed an increasing trend from June-September.

5. RELATIVE ABUNDANCE

Consolidated results on hydrography, phytoplankton pigments and primary productivity for the surface and column waters of the study area are given in Fig. 18.

5.1. Nutrients

The mean values of PO_4-P, NO_3-N and NO_2-N obtained for the euphotic column and the water column below euphotic zone per m^2 and per m^3 of water are given in Table 12 for comparison. Higher concentrations of nutrients (per m^3) were recorded in the euphotic column than in the column below the euphotic depth, although total production of nutrients increased in the latter since its column depth was more than the euphotic depth. Among the nutrients NO_3-N was more in concentration in the entire water column, followed by PO_4-P; and the mean values of PO_4-P, NO_3-N and NO_2-N for the season in the study area were 4.45, 6.41 and 0.94 mg at/m^3 respectively or it can be otherwise expressed as 4.45, 6.41 and 0.94 µg at/l respectively. The mean N/P ratio in the ecosystem was 1.65 during the southwest monsoon.

TABLE - 12

Relative abundance of nutrients in the water column of the study area (average of stations 1-3 expressed in mg at/m^2 & m^3

	PO_4-P	NO_3-N	NO_2-N	N/P ratio
Euphotic column (per m^2)	9.43	14.22	1.99	1.72
Average (per m^3)	6.29	9.48	1.33	
Below euphotic column (per m^2)	24.10	32.64	4.94	1.56
Average (per m^3)	4.02	5.44	0.82	

5.2. Phytoplankton

The relative abundance of major phytoplankton groups in the first half (June-July) and in the second half of the season (August-September) are presented in Table 13. Fortnightly and monthly fluctuations and abundance of major phytoplankton groups (%) are given in Figs. 19 and 20 respectively. The data indicated that certain groups of phytoplankton like Coscinodiscus, Ceratium, Rhizosolenia, Navicula and Biddulphia were relatively more in % in the first half of the season. The other major groups of phytoplankters like Chaetoceros, Fragilaria, Nitzschia and Pleurosigma were more in % during the second half of the season (August-September); and the others were dominated by freshwater forms especially in the first half of the season when the salinity was very less.

Table - 13

Relative abundance of major phytoplankton groups in % in the Cochin backwater during southwest monsoon season

Group	I - half (Jun-Jul)	II - half (Aug-Sep)	Whole season (Jun-Sep)
Coscinodiscus	21.25	15.00	18.13
Nitzschia	11.75	13.75	12.75
Skeletonema	10.00	10.00	10.00
Chaetoceros	--	17.50	8.75
Ceratium	13.75	2.50	8.12
Fragilaria	2.50	10.75	6.63
Rhizosolenia	6.25	3.75	5.0
Navicula	7.50	2.50	5.0
Pleurosigma	1.25	7.00	4.13
Biddulphia	2.50	1.25	1.87
Others	23.25	16.00	19.62

5.3. Phytoplankton pigments

Consolidated values of the study area on the relative abundance of phytoplankton pigments in the first half and second half of the season for the euphotic column and the column below euphotic zone are given in Table 14.

In the euphotic column the concentrations of chlorophyll 'a', 'c', carotenoids and phaeo-pigments were more in the second half of the season while chlorophyll 'b' concentration showed slight decline during the second half. The percentage of phaeo-pigment concentration in relation to total chlorophylls ranged between 22-25% and that in relation to the sum of total chlorophylls and carotenoids ranged between 19-24%. The ranges in the ratios of different phytoplankton pigments like chlorophyll 'b'/'a', 'c'/'a' and carotenoid/chl 'a' were 0.19-0.54, 0.23-0.66 and 0.14-0.35 and their mean values were 0.36, 0.45 and 0.26 respectively in the euphotic column of the study area.

In the column below euphotic zone, a similar trend was observed except in the case of chlorophyll 'b' which showed higher values in the second half of the season. The percentage of phaeo-pigments in relation to total chlorophylls ranged between 35-42% and in relation to the sum of total chlorophylls and carotenoids ranged between 29-36% between the first and second half of southwest monsoon season.

Table - 14

Relative abundance of phytoplankton pigments in the first half and second half of the season between the euphotic and below euphotic columns in the study area (Average of stations 1-3 expressed per m^3 of water)

Parameters		Euphotic column		Below euphotic column	
		Jun-Jul	Aug-Sep	Jun-Jul	Aug-Sep
Chlorophyll 'a'	(mg)	6.75	17.51	2.01	5.54
Chlorophyll 'b'	(")	3.49	3.21	0.30	1.33
Chlorophyll 'c'	(")	4.05	4.90	0.81	1.05
Total chlorophylls (a+b+c)	(")	14.29	25.63	3.14	7.902
Carotenoids	(")	1.30	5.71	0.59	2.02
Phaeo-pigments	(")	4.73	7.39	2.06	4.25

5.4. Primary productivity

The primary productivity (gross and net) in the euphotic column varied much between the first and second half of the season and very high rate of production was recorded in the second half of the season (Table 15). The N.P/G.P ratio was 0.66 and 0.59 for the respective period. In the surface waters N.P/G.P ratio ranged between 0.45-0.96 and in the water column between 0.45-0.95. Overall average net value for the entire study area worked out to 60% of gross production during the southwest monsoon season when the gross and

TABLE - 15

Relative abundance of gross and net primary production in the euphotic column of the study area (average of stations 1-3)

Season	Gross production ($g\ C/m^2/day$)	Net production ($g\ C/m^2/day$
I half (June-July)	0.669	0.439
II half (August-September)	2.029	1.191
Whole season (June-September)	1.349	0.815

net productivity were 1.349 and 0.815 $g\ C/m^2/day$ respectively in the euphotic column. In the surface waters assimilation number ranged between 3.57-11.87 and in the water column between 3.96-10.36 with their mean values as 7.61 and 6.19 respectively and the maximum was recorded in August at stations 2 & 3.

Fig. 2. FORTNIGHTLY VARIATIONS IN SURFACE WATERS AT STATION-1.

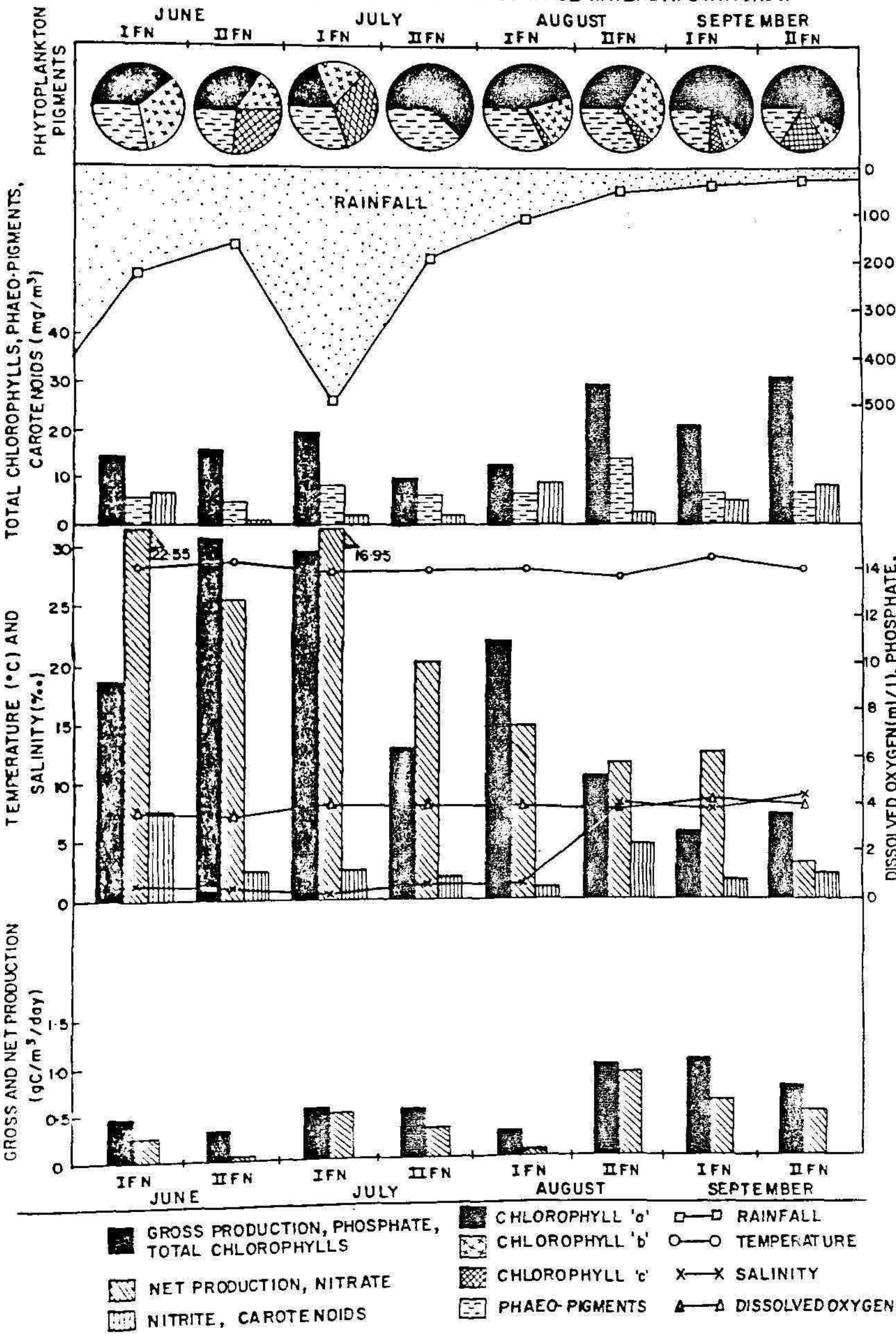


Fig. 3. FORTNIGHTLY VARIATIONS IN SURFACE WATERS AT STATION_ 2.

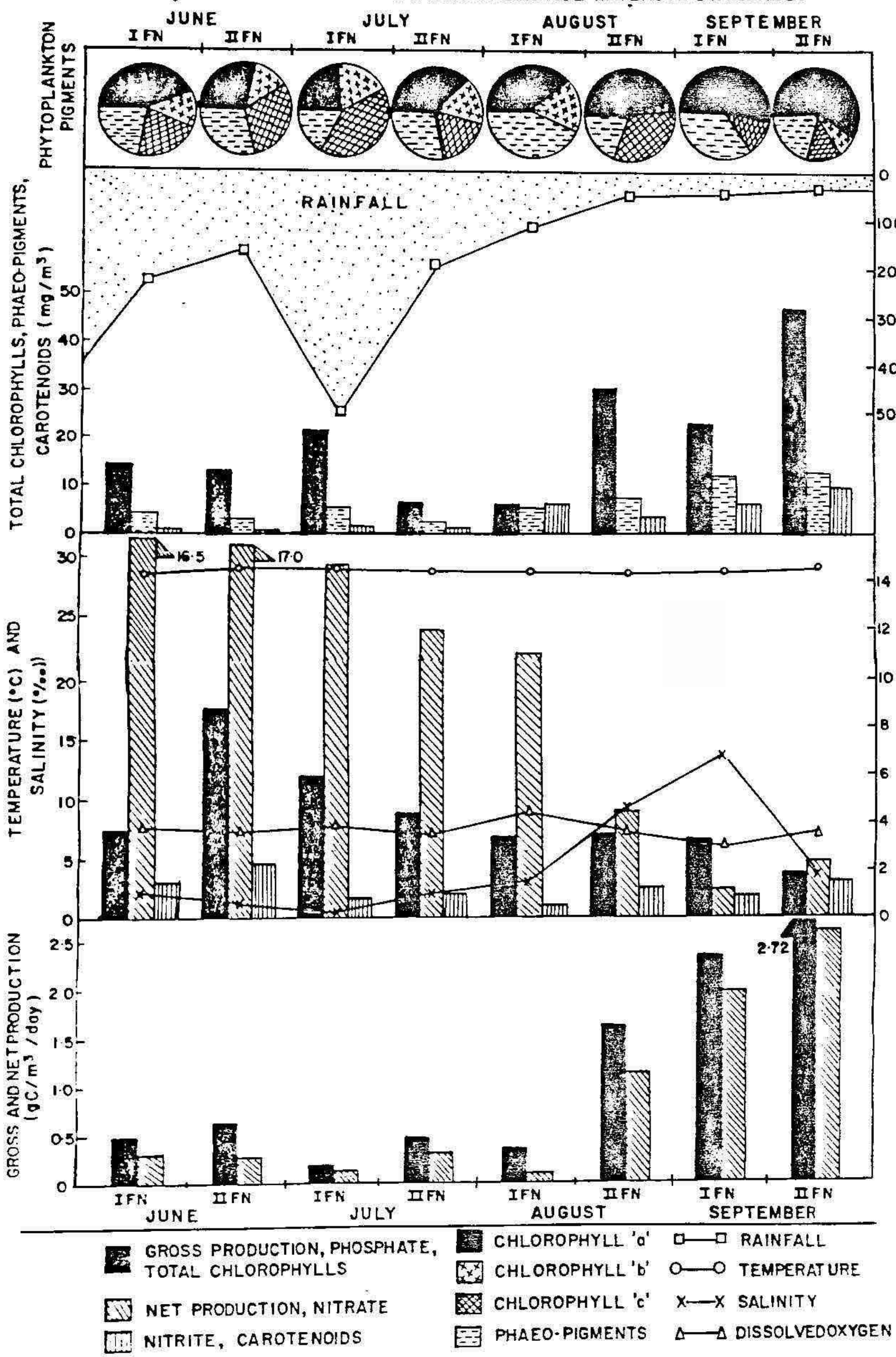


Fig. 4. FORTNIGHTLY VARIATIONS IN SURFACE WATERS AT STATION. 3.

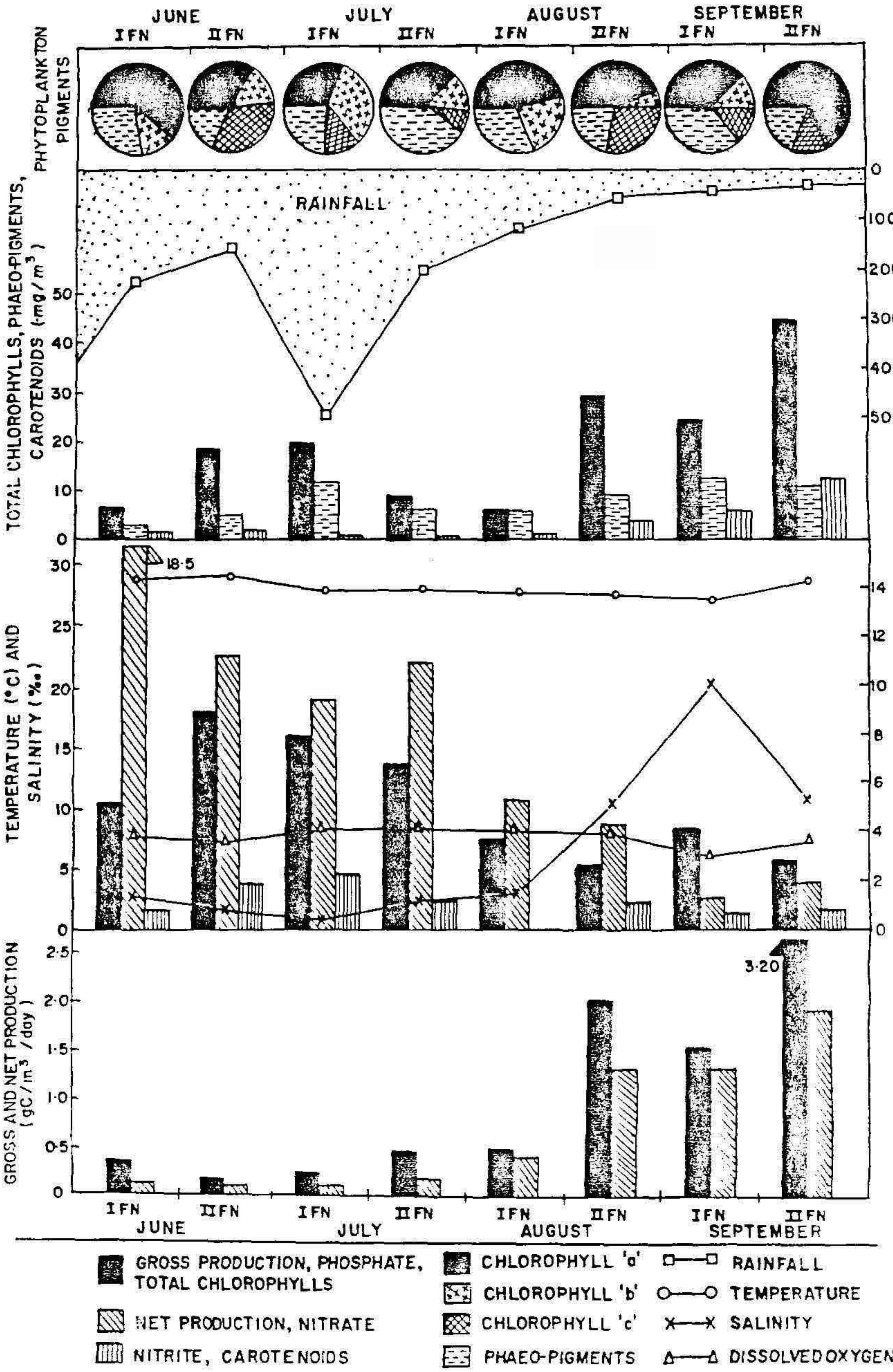


Fig. 5. FORTNIGHTLY VARIATIONS IN SURFACE WATERS(AVERAGE OF STATIONS 1,2&3)

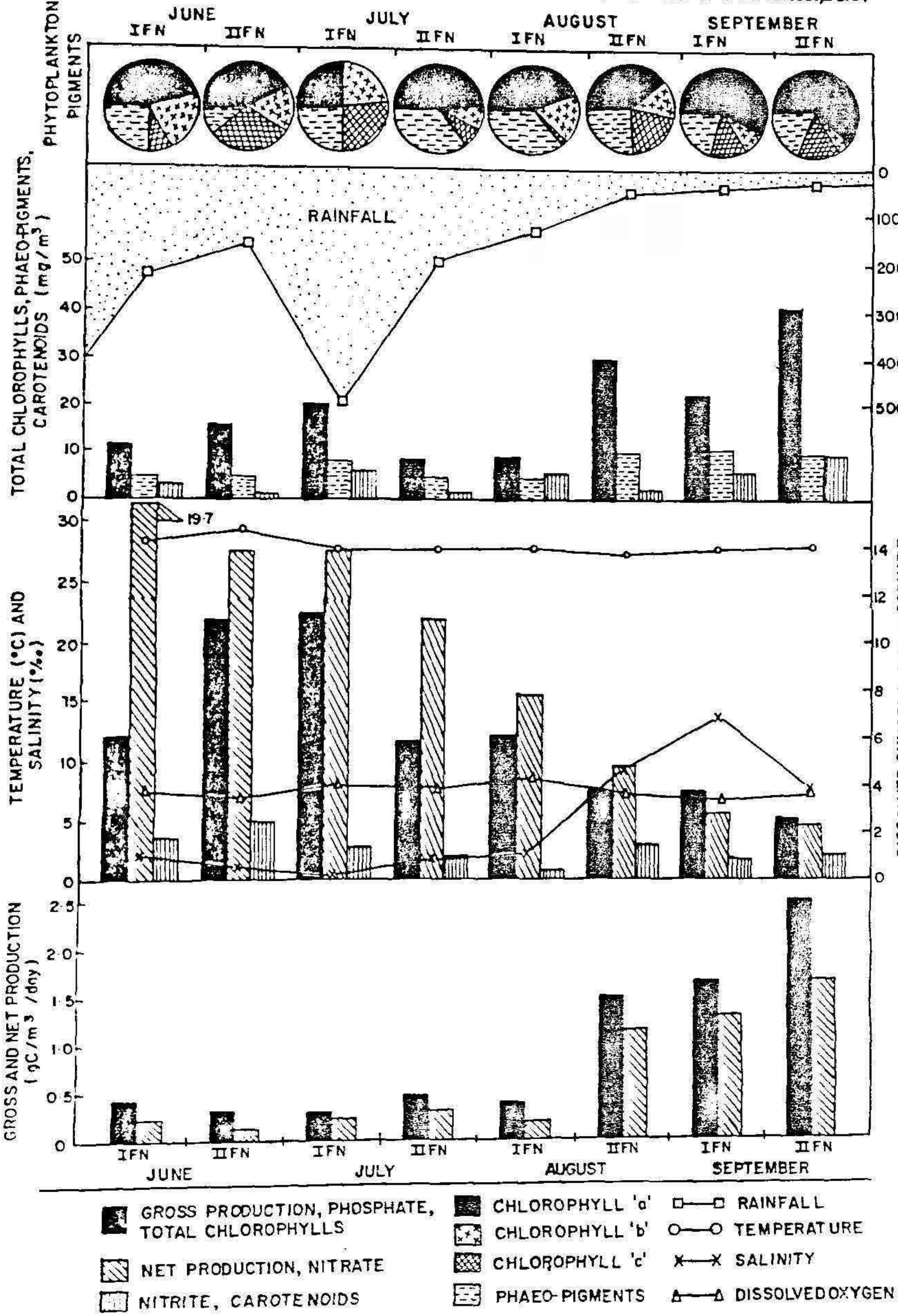


Fig. 6. MONTHLY VARIATIONS IN SURFACE WATERS AT STATION_1.

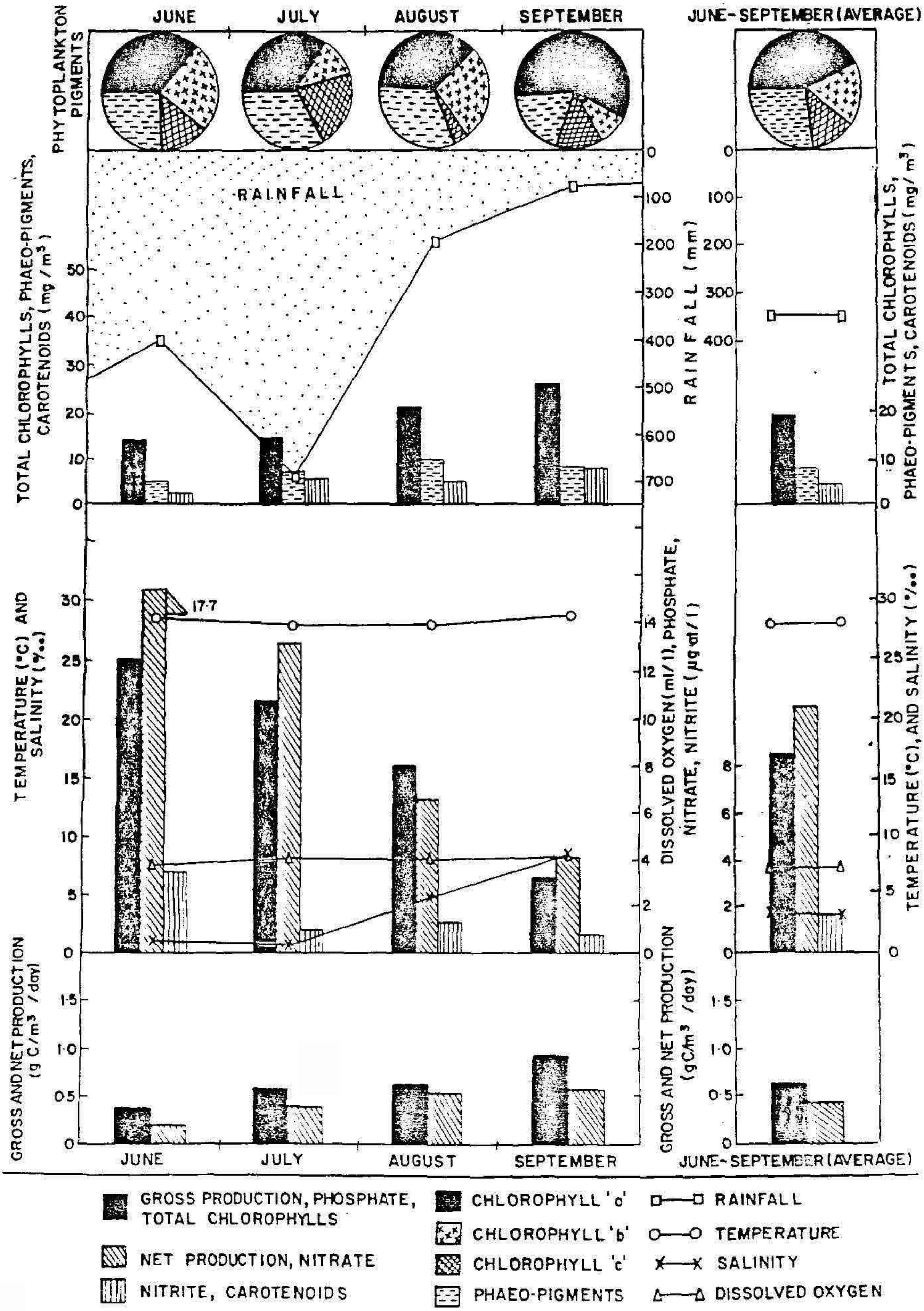


Fig. 7. MONTHLY VARIATIONS IN SURFACE WATERS AT STATION-2.

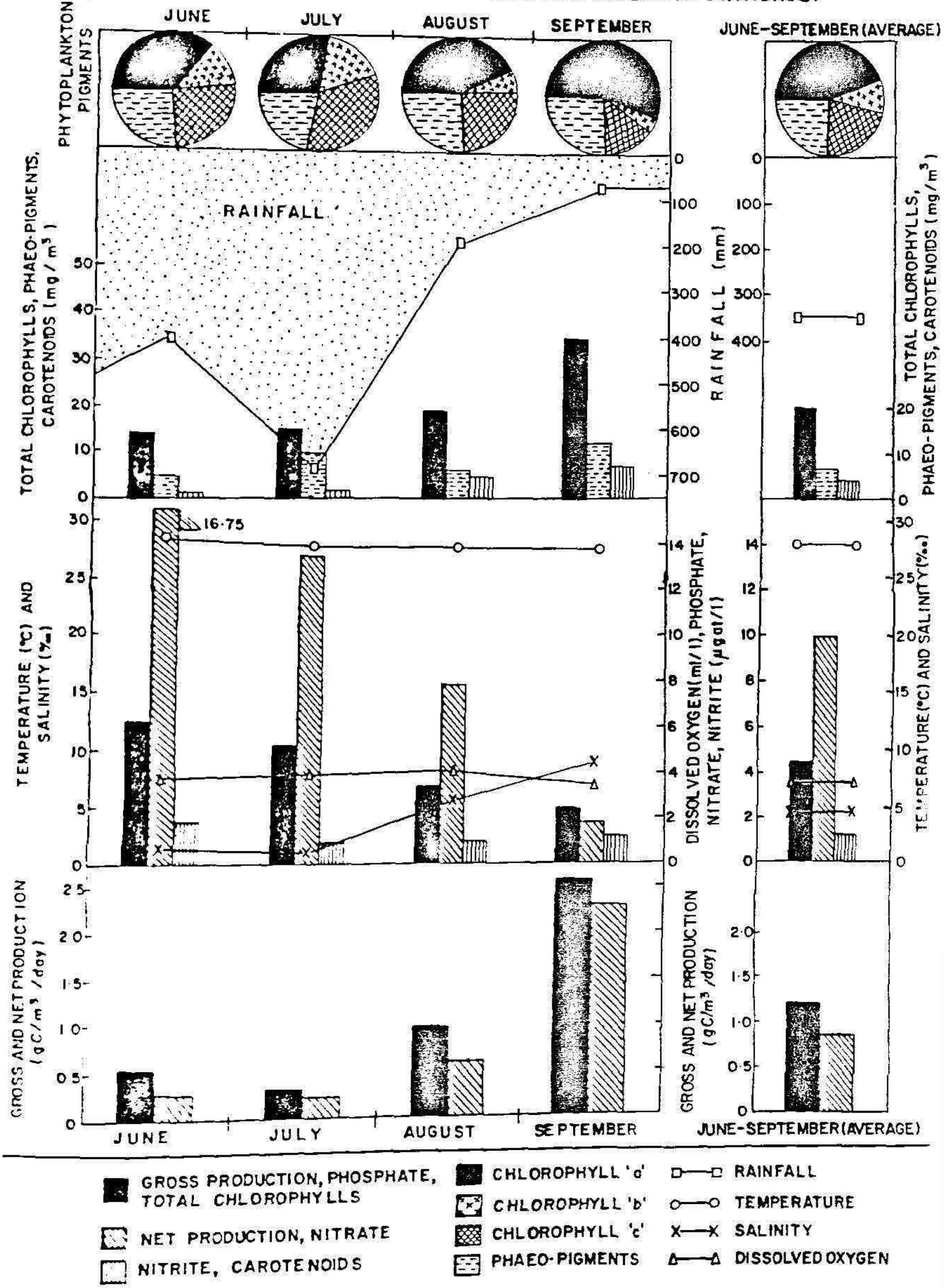


Fig. 8. MONTHLY VARIATIONS IN SURFACE WATERS AT STATION. 3.

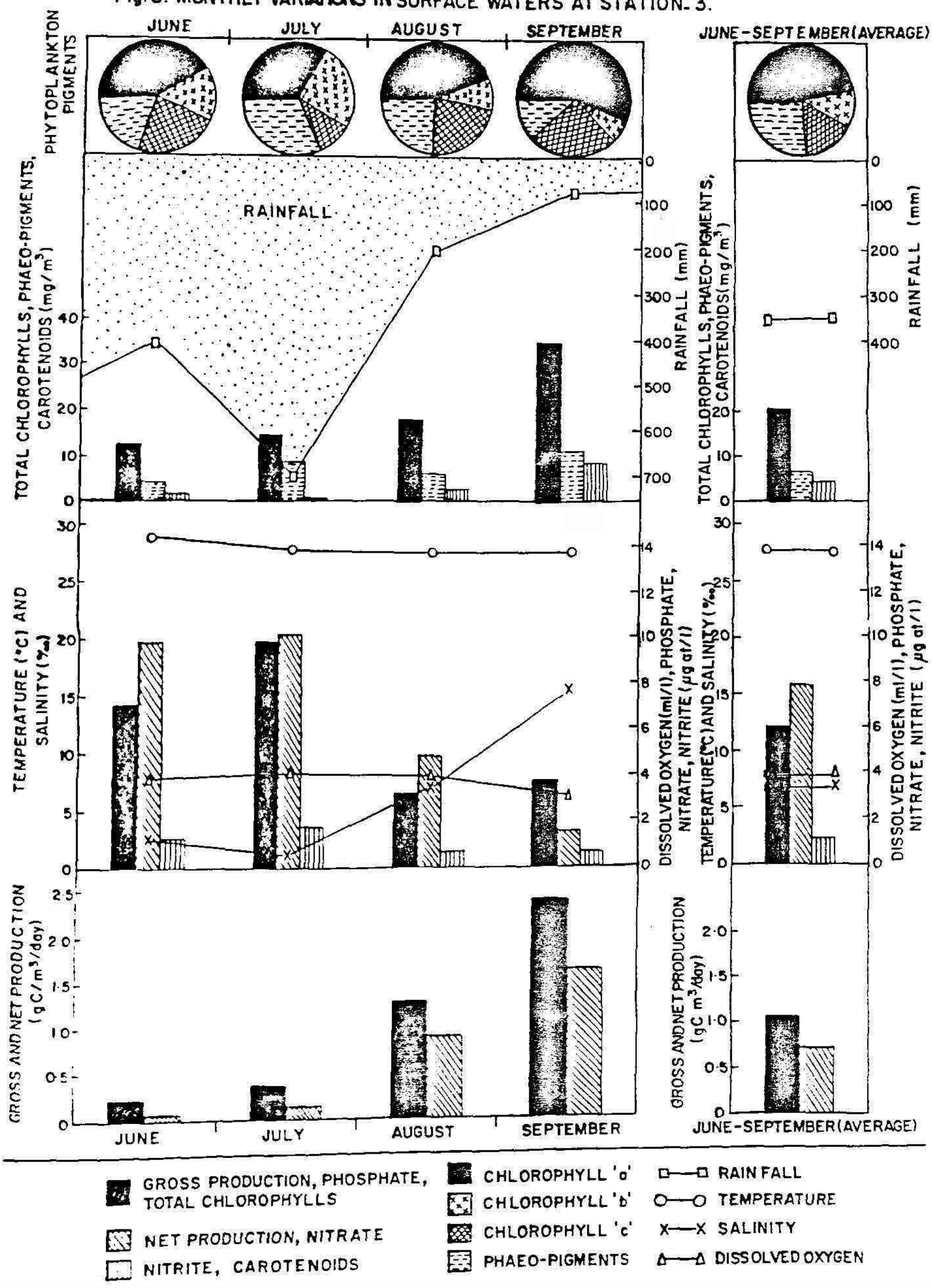


Fig. 9. MONTHLY VARIATIONS IN SURFACE WATERS (AVERAGE OF STATIONS 1, 2 & 3)

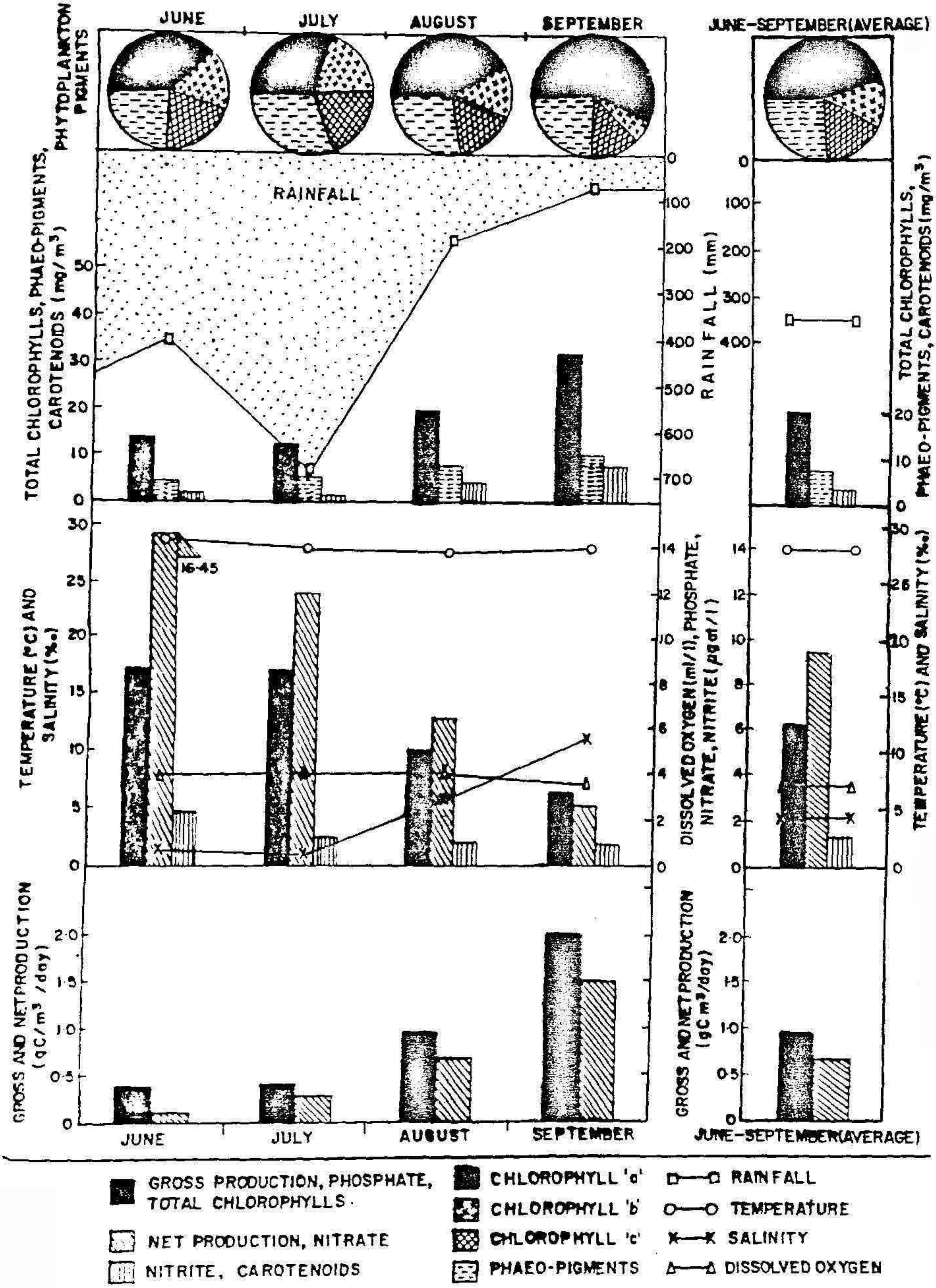


Fig. 10. FORTNIGHTLY VARIATIONS IN THE WATER COLUMN AT STATION- 1.

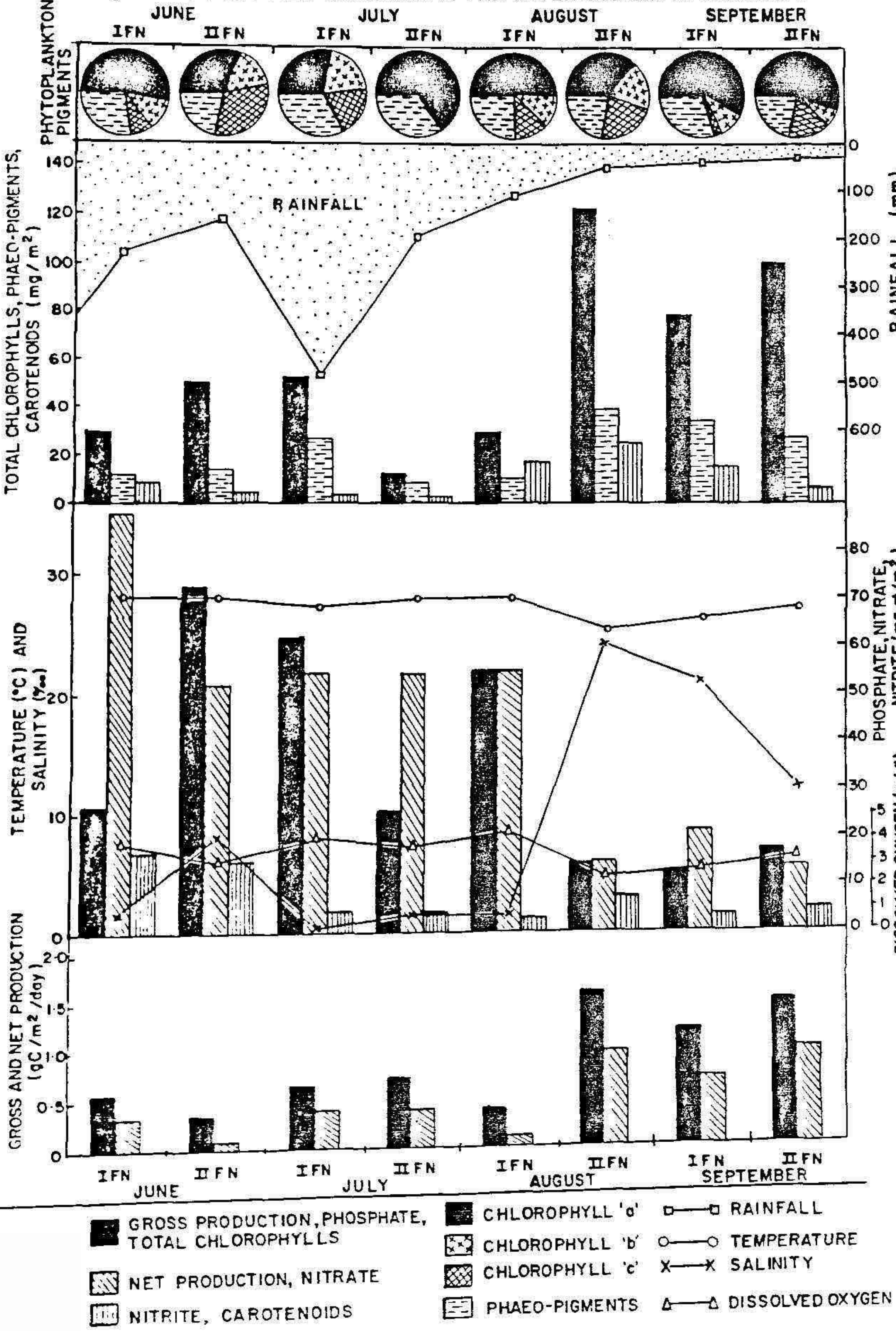


Fig. 11. FORTNIGHTLY VARIATIONS IN THE WATER COLUMN AT STATION-2.

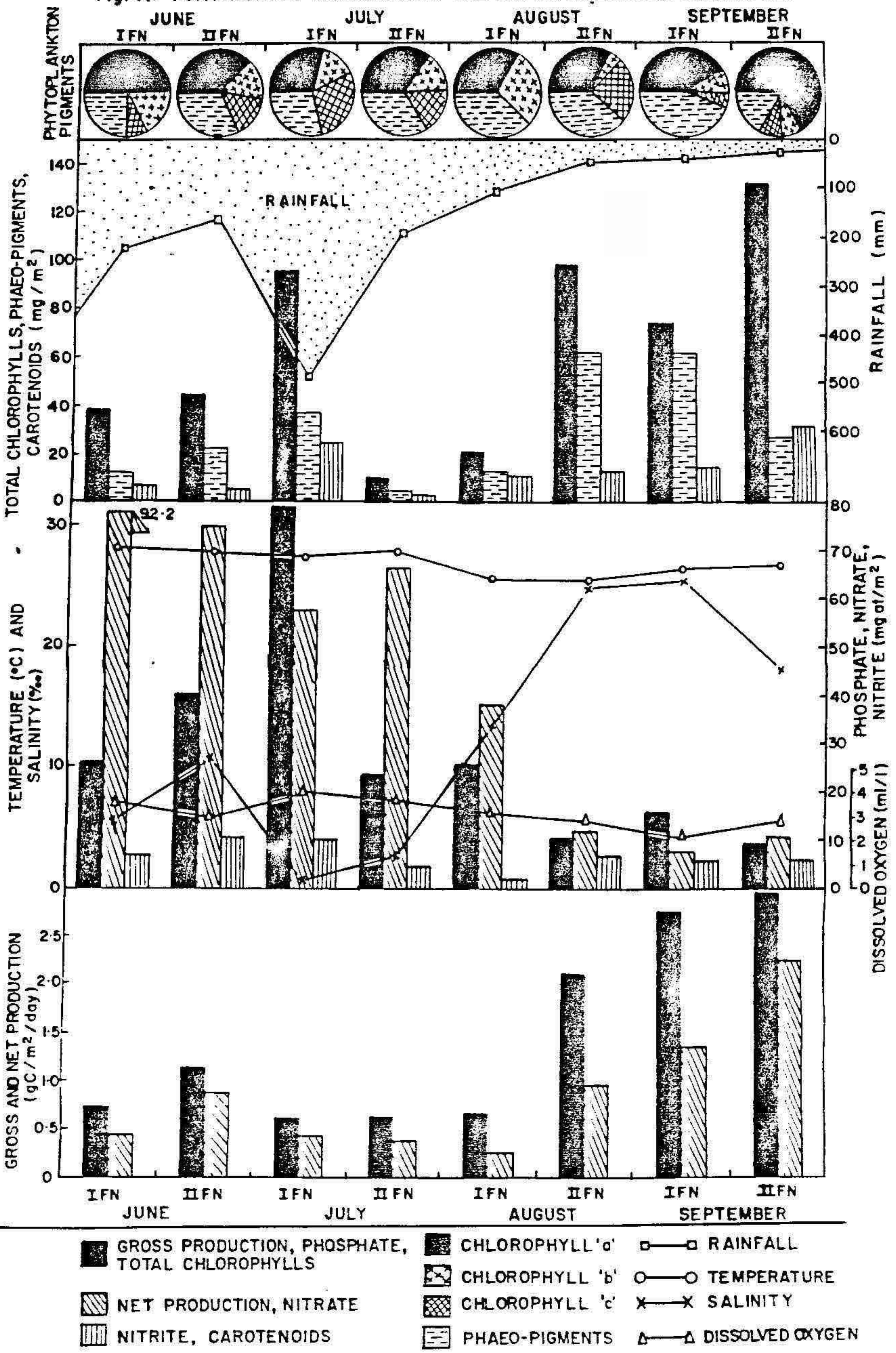


Fig. 12. FORTNIGHTLY VARIATIONS IN THE WATER COLUMN AT STATION 3.

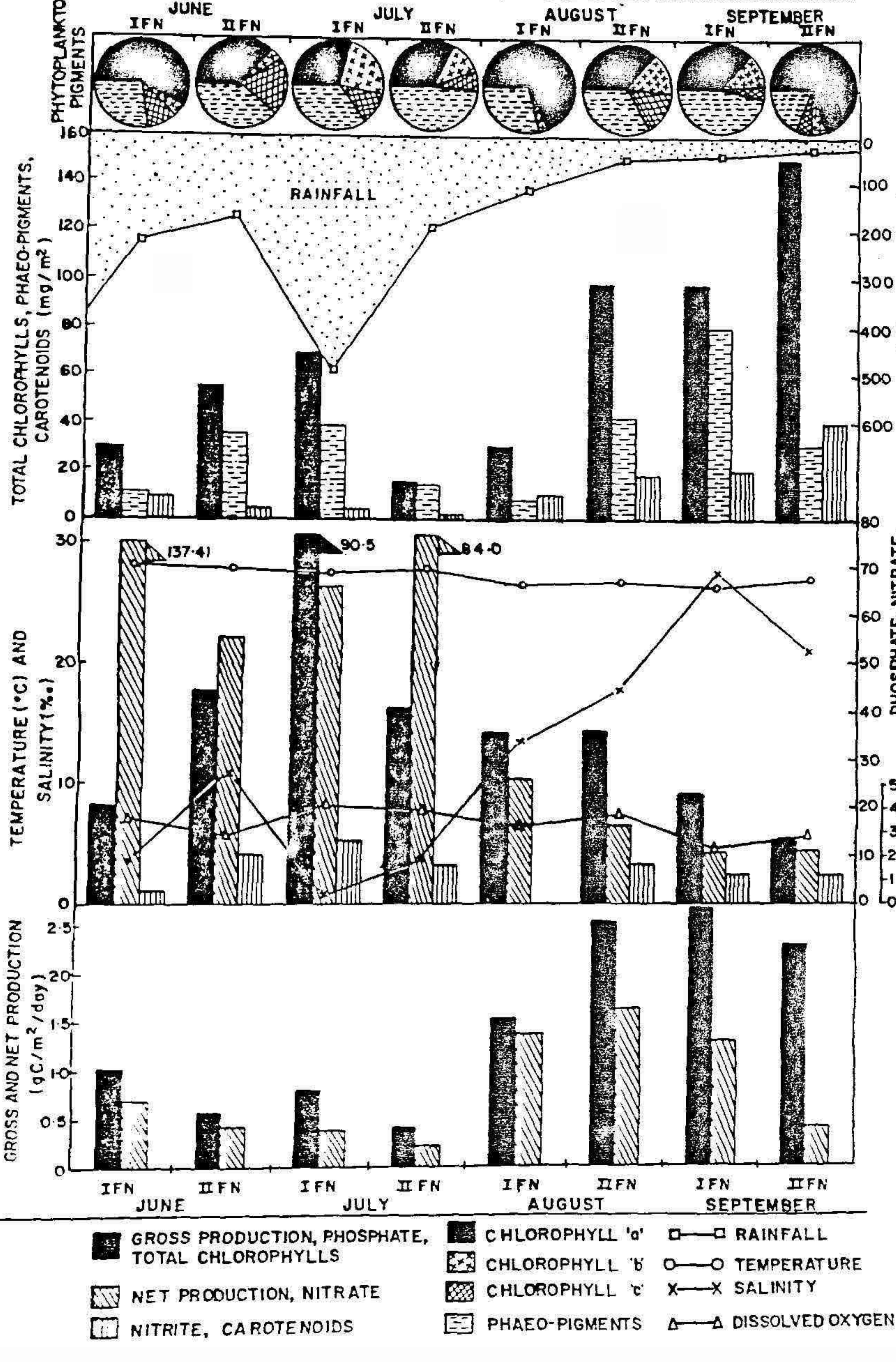


Fig. 13. FORTNIGHTLY VARIATIONS IN THE WATER COLUMN (AVERAGE OF STATIONS 1, 2 & 3)

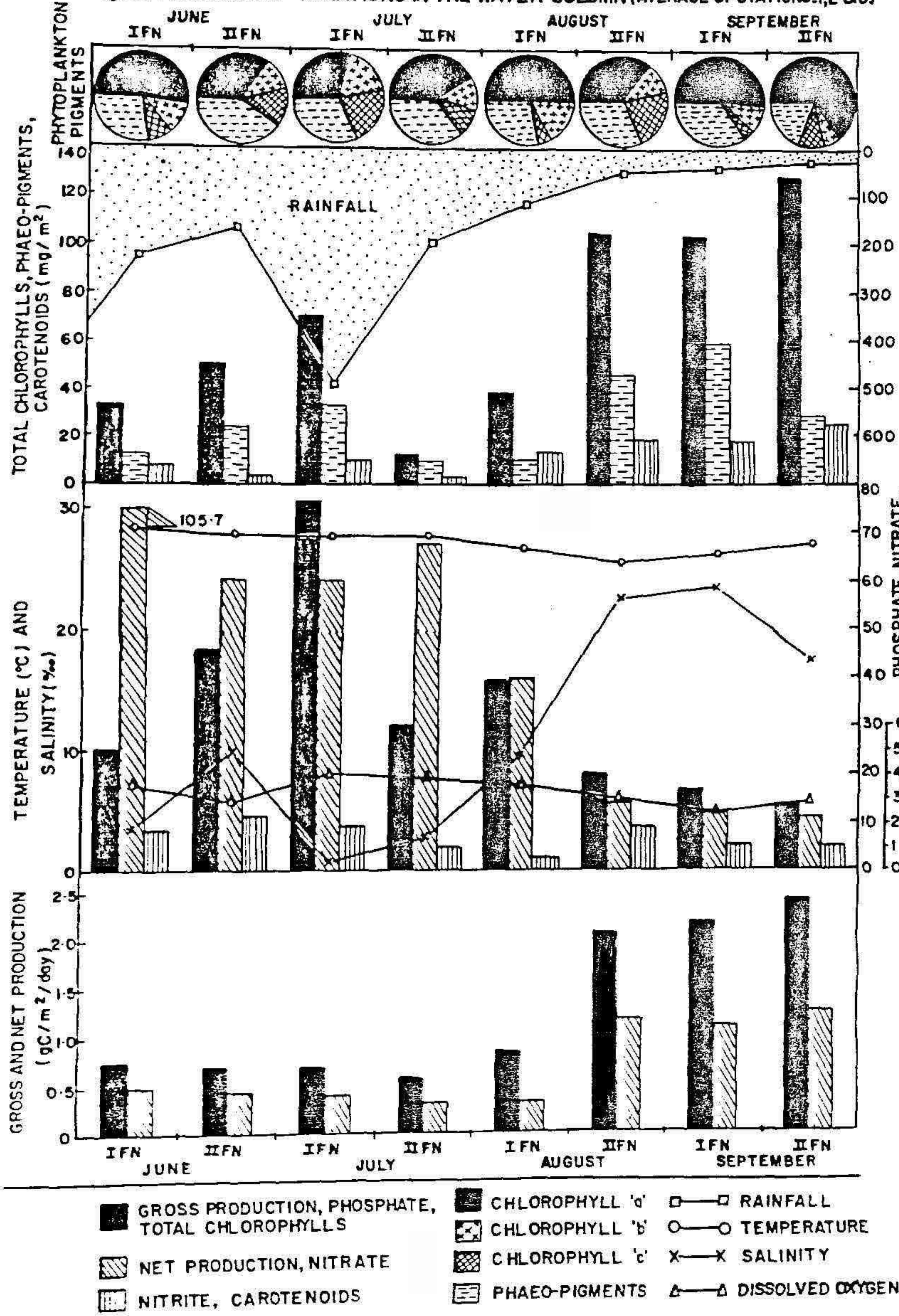


Fig. 14. MONTHLY VARIATIONS IN THE WATER COLUMN AT STATION- 1.

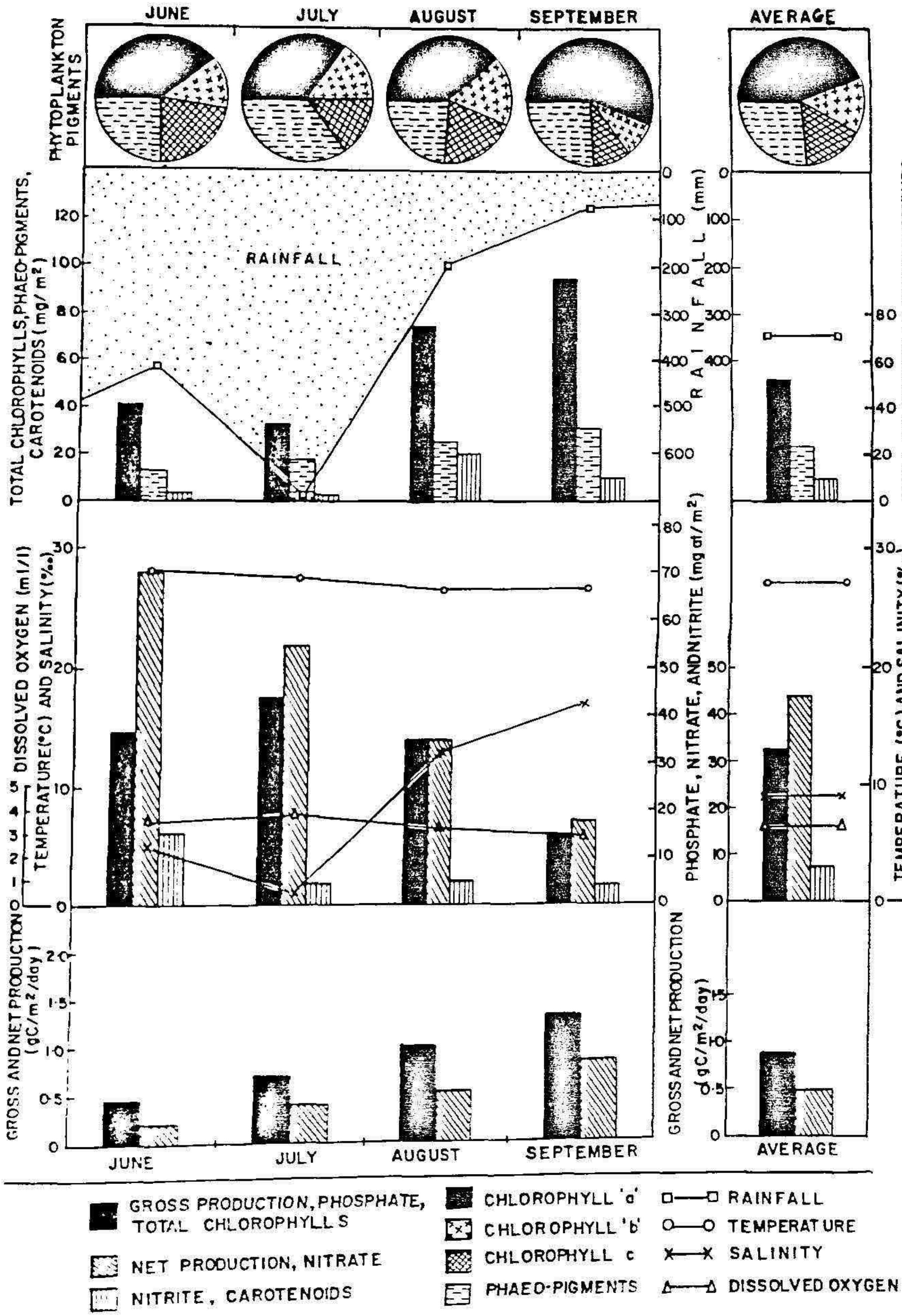


Fig. 15. MONTHLY VARIATIONS IN THE WATER COLUMN AT STATION_2.

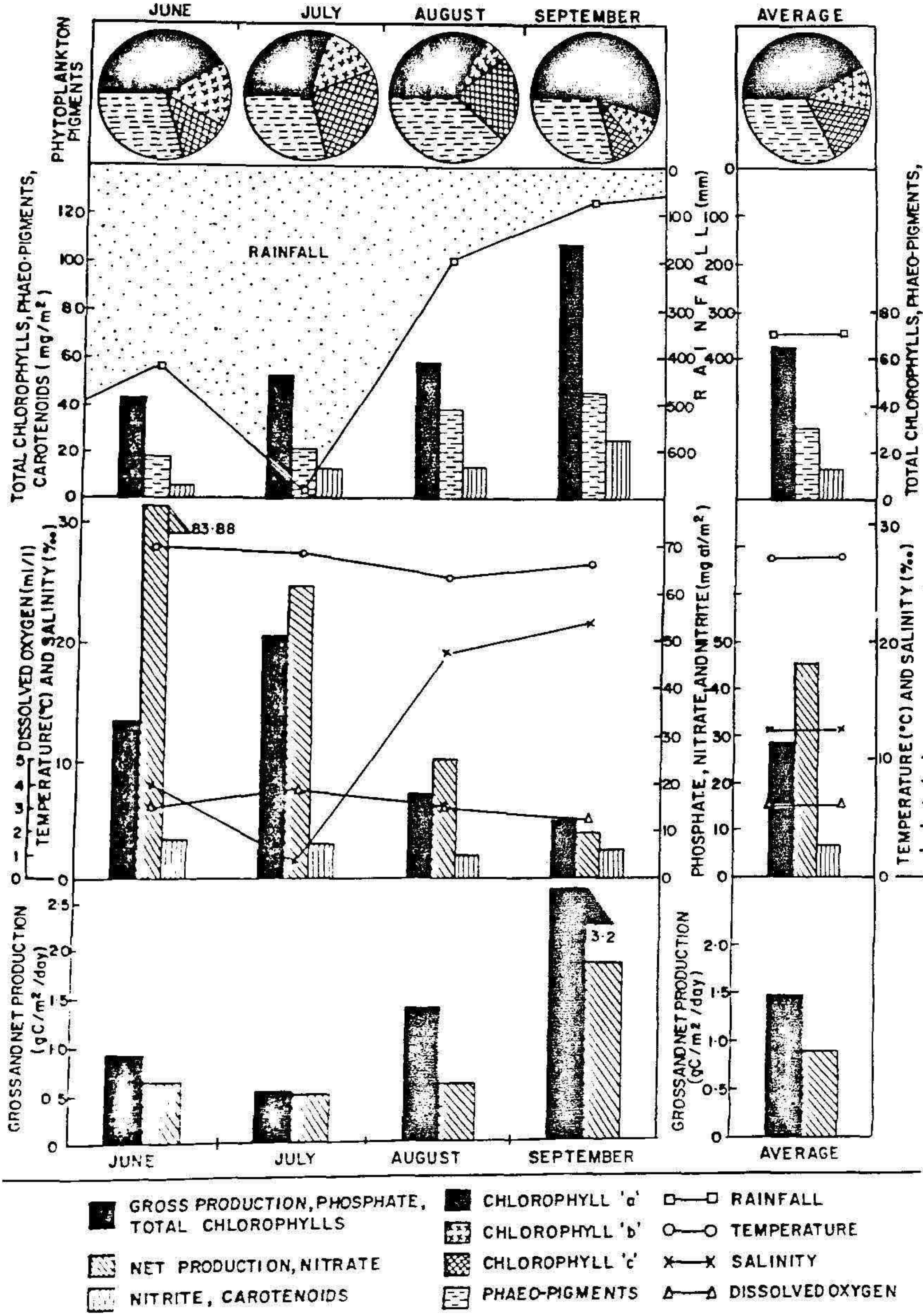


Fig.16. MONTHLY VARIATIONS IN THE WATER COLUMN AT STATION- 3.

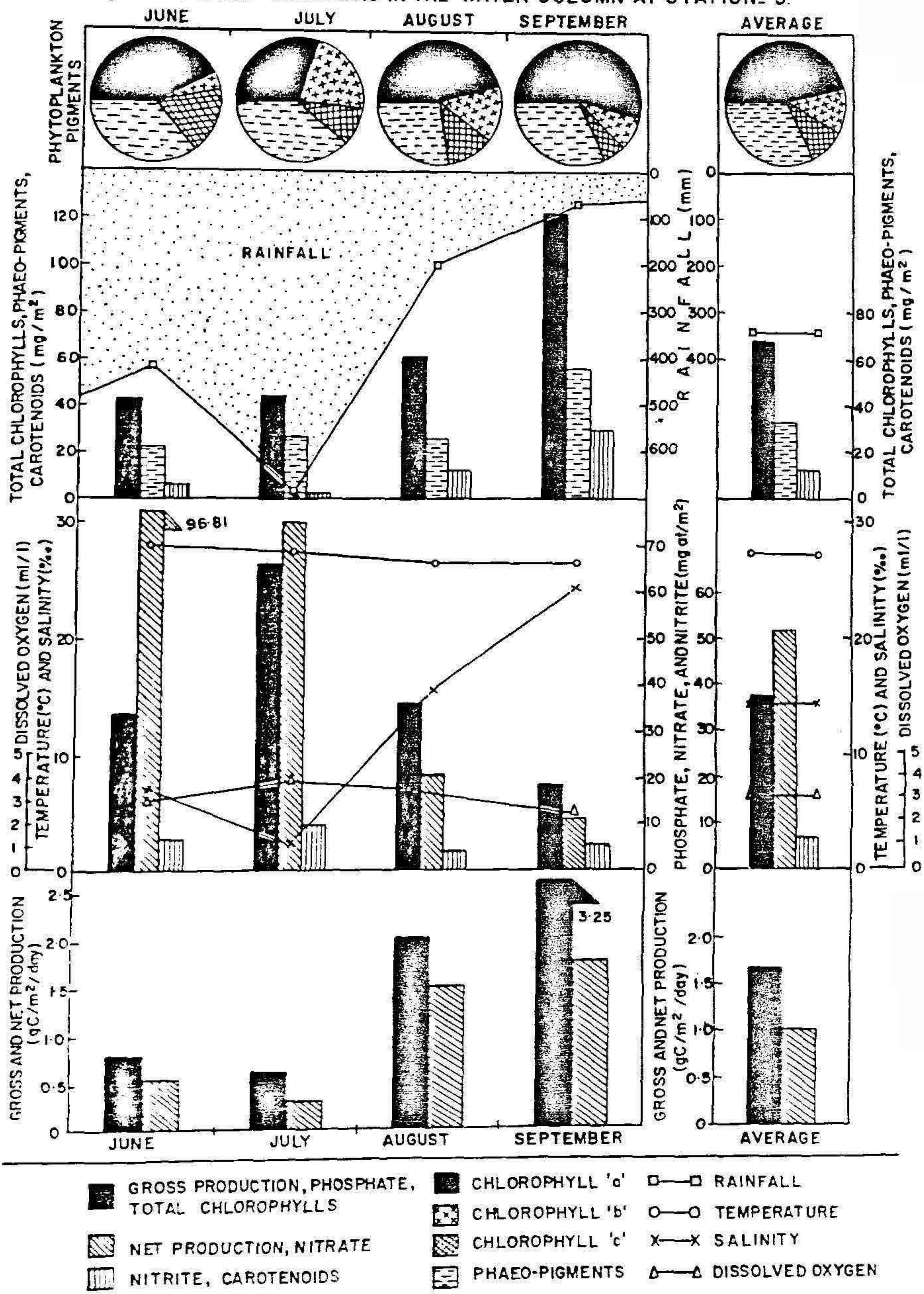


Fig. 17. MONTHLY VARIATIONS IN THE WATER COLUMN (AVERAGE OF STATIONS-1,2 & 3.)

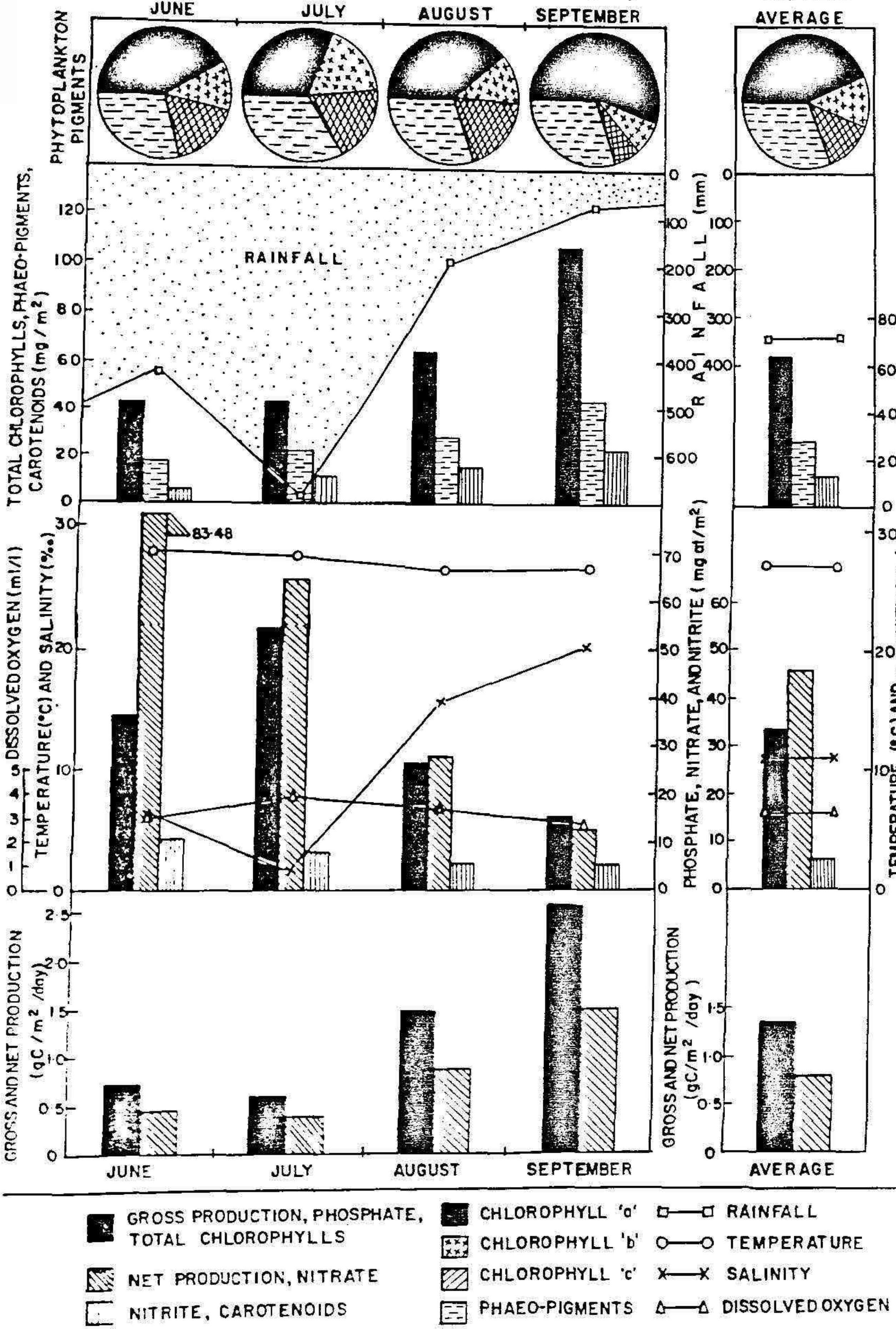


Fig. 18. MONTHLY CONSOLIDATED DATA (AVERAGE OF 3 STATIONS)
(HYDROGRAPHY, PHYTOPLANKTON PIGMENTS AND PRIMARY PRODUCTIVITY)

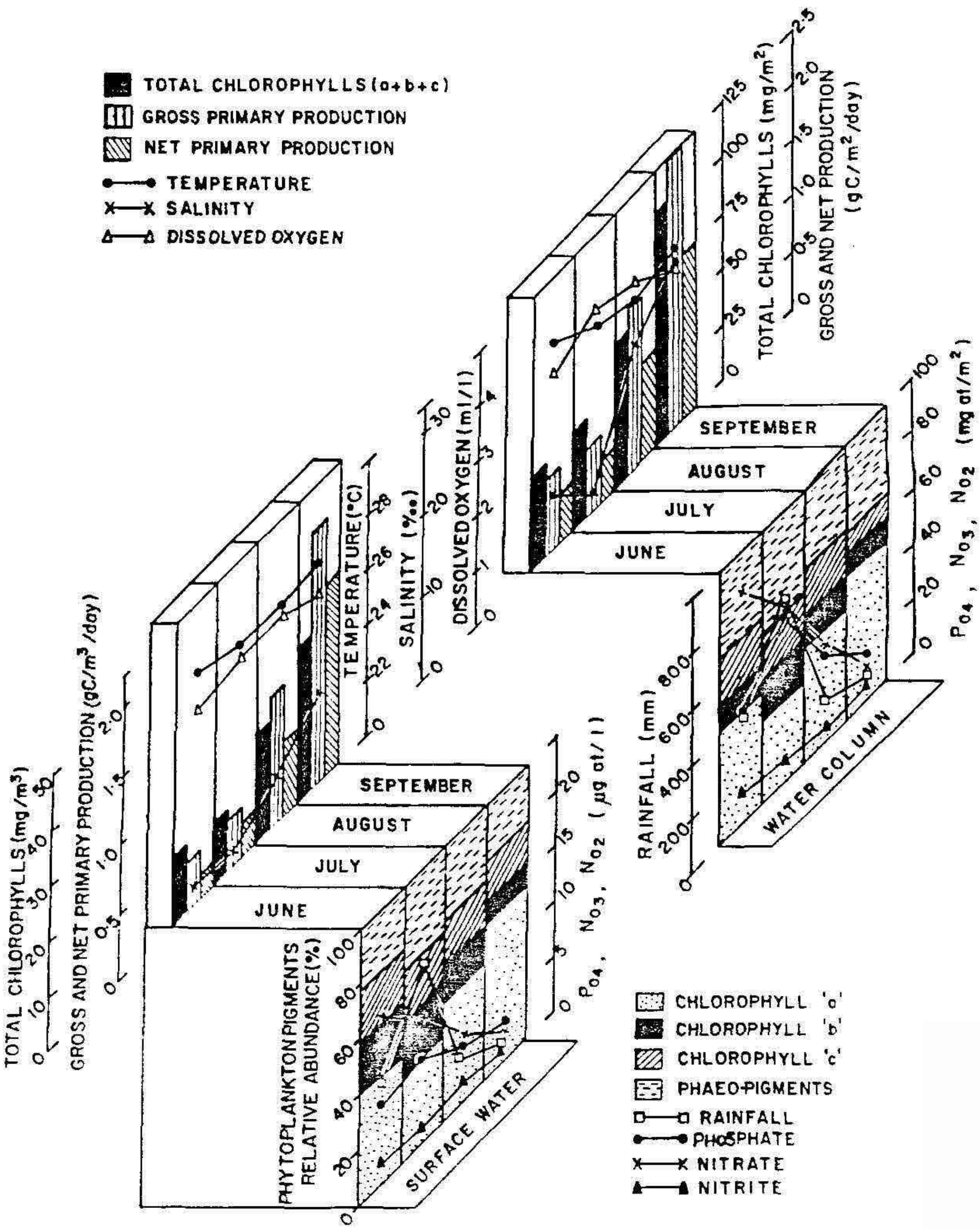


Fig.19. FORTNIGHTLY FLUCTUATIONS AND RELATIVE ABUNDANCE OF PHYTOPLANKTON GROUPS (%)

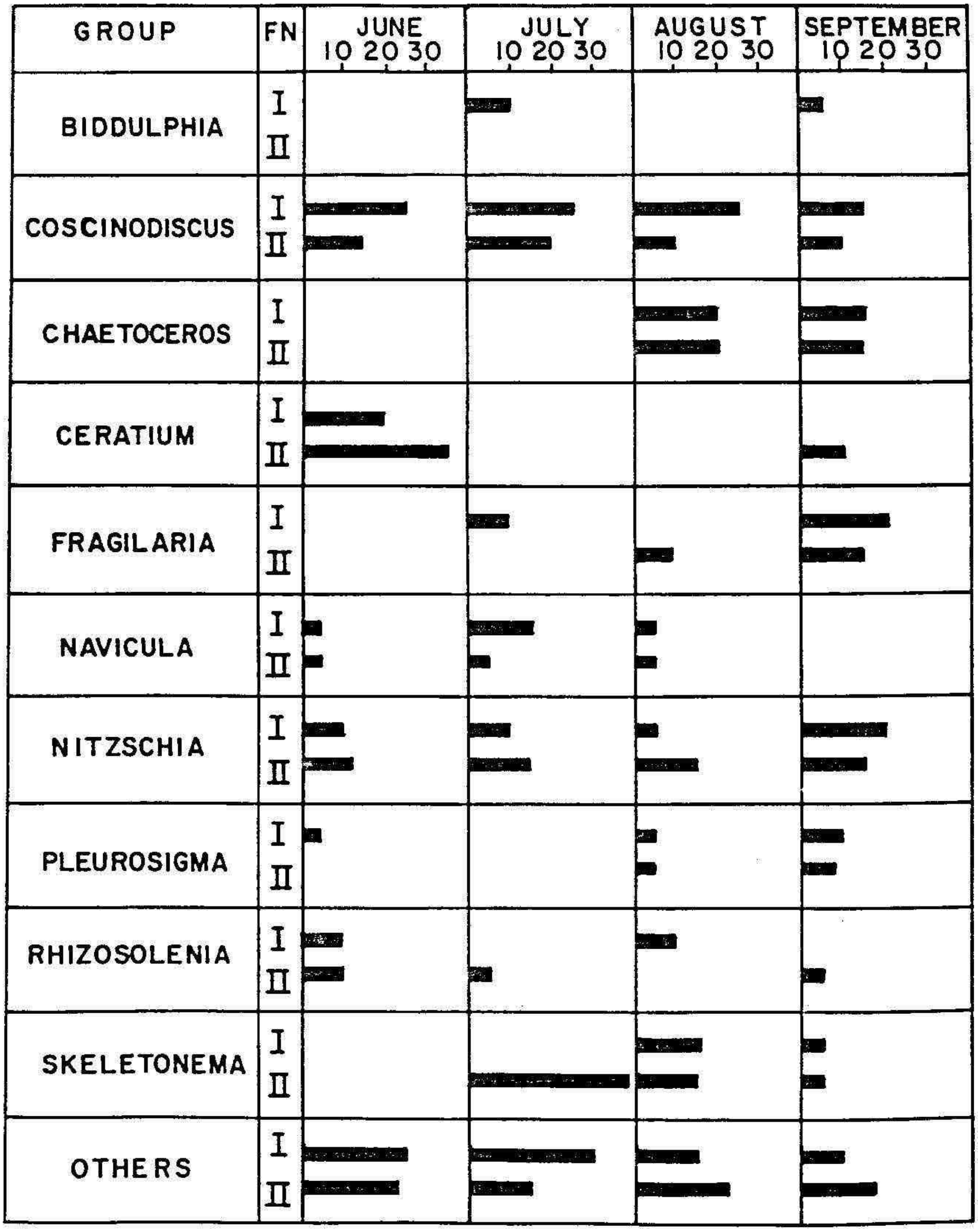
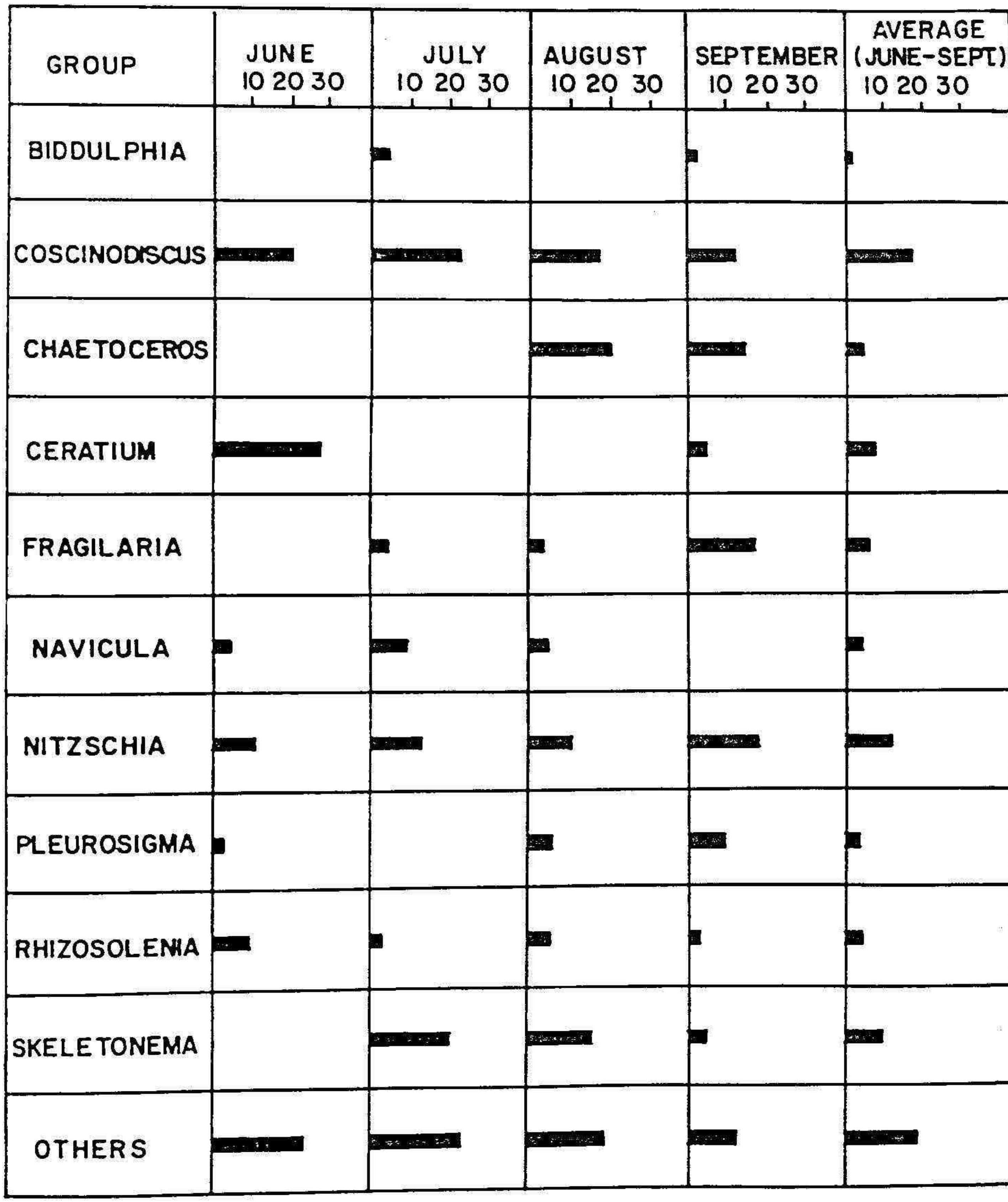


Fig. 20. MONTHLY FLUCTIONS AND RELATIVE ABUNDANCE OF PHYTOPLANKTON GROUPS (%)



6. QUANTITATIVE ASSESSMENT

Based on 42 primary productivity experiments conducted in the study area (by simulated *in situ* method) during June-September, the average gross production was estimated in the water column as 1.349 g C/m^2/day and net production was 0.815 g C/m^2/day in the monsoon season. The amount of gross and net production for this period (June-September) was estimated as 164.58 and 99.43 g C/m^2, which when converted per km^2 area worked out to 164580 and 99430 kg carbon respectively. Thus a net production of 99.43 tonnes of carbon/km^2 has been estimated in the backwater around the study area for the period June-September 1990 and that an estimated amount equivalent to 65150 kg carbon/km^2 forming 40% of gross production would be spent in the primary level itself.

To confirm the productive potential of the phytoplankton pigments below the photosynthetic zone, an experiment was conducted in July 1990 during the diurnal observation at the barmouth station (Station 3) where bihourly water samples were collected from surface and near the bottom and productivity experiments were conducted on the deck of R.V. *Cadalmin* by light and dark method under natural light available for the surface water and found high production of 0.951 g C/m^3/day for the water sample collected at highest tide and the average gross production of 0.532 g C/m^3/day and net production of 0.295 g C/m^3/day were estimated in the bottom waters below

Table - 16

Influence of light, time and tide on primary productivity

Time (hrs)	Tidal amplitude (cm)	Surface g C/m^3/day		Near-bottom g C/m^3/day	
		Gross Prod.	Net Prod.	Gross Prod.	Net Prod.
0630	11	0.071	0.070	0.071	0.052
0830	0	0.143	0.071	0.214	0.071
1030	11	0.502	0.380	0.716	0.644
1230	31	0.787	0.716	0.786	0.285
1430	45	0.645	0.573	0.951	0.429
1630	35	0.578	0.315	0.452	0.287
Average/day		0.454	0.354	0.532	0.295

Note: Surface and bottom samples (Light bottles) were uniformly exposed to direct sunlight for incubation.

the euphotic zone (Table 16). The gross values indicated that the bottom waters were more productive than the surface waters while the net productivity was relatively less.

7. INFLUENCE OF HYDROGRAPHY ON PIGMENTS AND PRODUCTIVITY

7.1. Influence of rainfall

Rainfall data showed inverse relationship with primary production and chlorophyll concentration eventhough more nutrients were available. In the first half of the season (June-July) chlorophyll production was very less when the total rainfall was 1079 mm and in the second half (August-September) very high concentration of total chlorophylls and primary production were observed when the rainfall was only 261 mm. Reduction in rainfall in August-September within the monsoon season has influenced the productivity to the high level. The small decline in the intensity of rainfall during June resulted in a small peak in pigment concentration; and the subsequent heavy rainfall (484 mm) during the first fortnight of July affected the phytoplankton production as evidenced by the low concentration of total chlorophylls in the next fortnight (Figs. 2-5 & 10-13).

7.2. Influence of time and tide

Generally morning hours are considered to be good for biological sampling and it is a general impression that forenoon experiments give better productivity results than in the afternoon. To confirm this, a date, when the highest tide was occurring in the afternoon was selected for diurnal productivity experiments to differentiate the forenoon time and high tide. The experiments revealed that primary production was very low in the morning hours (when the tide was low) and more in the noon and afternoon when the highest tide was forming (Table-16) and indicated that tide is more related to productivity than time. The average concentration of total chlorophylls also revealed the same fact.

7.3. Influence of temperature, salinity and dissolved oxygen

Since the water temperature did not show much variation in the euphotic column during this season, its influence on productivity was not significant. Salinity was found to influence productivity and a direct relationship was noticed with primary production. Thus production was very low during June-July when the salinity of surface water was very low. Dissolved oxygen in the surface layers did not show much variation and hence no remarkable relationship with variation in productivity was noticed during the first and second half of the season. The influence of salinity, temperature and dissolved oxygen on the distribution and abundance of phytoplankters are presented in Table 17.

7.4. Influence of nutrients

The data revealed that although exceptionally high concentrations of nutrients were recorded in the peak monsoon months (June-July), generally low primary production was noticed indicating that it is not the limiting factor on product-

Table - 17

Period of abundance of major phytoplankton groups in relation to hydrographic parameters during June - September 1990

Group	Month of abundance	Salinity (‰)	Temperature (°C)	Dissolved oxygen (ml/l)	PO_4-P (µg at/l)	NO_3-N (µg at/l)	NO_2-N (µg at/l)
Coscinodiscus	Jul	0.92	27.87	3.92	8.56	12.39	1.26
Nitzschia	Sep	10.72	28.02	3.52	3.18	2.64	0.89
Skeletonema	Jul	0.92	27.87	3.92	8.56	12.39	1.26
Chaetoceros	Aug	5.75	27.71	3.96	4.89	6.42	0.96
Ceratium	Jun	1.70	28.63	3.70	8.56	16.45	2.22
Fragilaria	Sep	10.72	28.02	3.52	3.18	2.64	0.89
Rhizosalenia	Jun	1.70	28.63	3.70	8.56	16.45	2.22
Navicula	Jul	0.92	27.87	3.92	8.56	12.39	1.26
Pleurosigma	Sep	10.72	28.02	3.52	3.18	2.64	0.89
Biddulphia	Jul	0.92	27.87	3.92	8.56	12.39	1.26

ivity in monsoon season, though the nutrient-phytoplankton relationship is an established one. The influence of nutrients studied on phytoplankters are presented in Table 17.

7.5. Statistical analysis

7.5.1. Surface data: Correlation matrix showed that gross production is mainly dependent upon the following variables in the order, total chlorophylls, carotenoids, nitrate, phaeo-pigments, salinity and phosphate. While nitrate and phosphate showed inverse relationship with production, salinity, total chlorophylls, phaeo-pigments and carotenoids showed positive relationship. These variables gave a regression coefficient of 0.83 which was significant at 1% level. Thus about 83% of the variations in production was accounted for by these explanatory variables. Correlation coefficients of different independent and dependent variables are presented in Table 18.

7.5.2. Euphotic zone: Correlation matrix showed that gross production is mainly dependent upon the following variables in the order salinity, total chlorophylls, phaeo-pigments, nitrate, dissolved O_2, temperature, carotenoids and phosphate. While nitrate, temperature, dissolved oxygen and phosphate showed inverse relationship with production, salinity, total chlorophylls, phaeo-pigments and carotenoids showed positive relation ship. These variables gave a regression coefficient of 0.86 which was significant at 1% level. Thus about 86% of the variations in production was accounted for by these explanatory variables. Correlation coefficients of different independent and dependent variables are presented in Table 19.

Table - 18

Statistical analysis of surface data of the study area

Mean of the dependent variable (Gross Prod.) : 965.083

SD : 966.708

Mean and SD of independent variable:

CHARACTER		Mean	SD
1.	Temperature	28.06	0.515
2.	Salinity	4.776	5.157
3.	Dissolved Oxygen	3.774	0.365
4.	PO_4-P	6.302	3.969
5.	NO_3-N	9.48	6.079
6.	NO_2-N	1.33	0.883
7.	Total chlorophylls	19.85	11.415
8.	Phaeo-pigments	7.077	3.415
9.	Carotenoids	3.63	3.339

Correlation matrix for the set

	1	2	3	4	5	6	7	8	9	10
1	1.0									
2	-0.49	1.0								
3	0.20	-0.61	1.0							
4	0.22	-0.51	0.17	1.0						
5	0.43	-0.72	0.29	0.50	1.0					
6	0.30	-0.29	-0.19	0.51	0.45	1.0				
7	-0.17	0.51	-0.35	-0.33	-0.60	0.03	1.0			
8	-0.51	0.61	-0.44	-0.13	-0.60	0.07	0.71	1.0		
9	-0.11	0.44	-0.06	-0.39	-0.52	-0.25	0.62	0.41	1.0	
10	-0.22	0.59	-0.44	-0.53	-0.66	-0.15	0.81	0.65	0.67	1.0

$R^2 = 0.83$

Table - 19

Statistical analysis of the euphotic column data of the study area

Mean of the dependent variable : 1294.33
(Gross Prod.)
SD : 903.239

Mean and SD of independent variables:

CHARACTER	Mean	SD
1. Temperature	27.15	0.907
2. Salinity	11.28	9.321
3. Dissolved oxygen	3.28	0.593
4. Phosphate	9.24	5.509
5. Nitrate	14.01	8.933
6. Nitrite	1.95	1.209
7. Total chlorophylls	29.89	18.51
8. Phaeo-pigments	10.63	5.58
9. Carotenoids	5.29	5.275

Correlation matrix for the set

	1	2	3	4	5	6	7	8	9	10
1	1.0									
2	-0.81	1.0								
3	0.60	-0.87	1.0							
4	0.48	-0.56	0.40	1.0						
5	0.67	-0.74	0.50	0.45	1.0					
6	0.35	-0.19	0.05	0.53	0.38	1.0				
7	-0.38	0.58	-0.39	-0.32	-0.59	0.04	1.0			
8	-0,52	0.59	-0.41	-0.08	-0.61	0.09	0.73	1.0		
9	-0.27	0.45	-0.29	-0.44	-0.57	-0.26	0.69	0.47	1.0	
10	-0.59	0.79	-0.59	-0.57	-0.71	-0.19	0.76	0.72	0.57	1.0

$R^2 = 0.86$

D I S C U S S I O N

On the basis of monsoon effects and associated climatic changes, three seasons are recognised in a year along the southwest coast of India, viz. the stable premonsoon (February-May), the unstable monsoon (June-September) and the relatively less stable postmonsoon season (October-January). The monsoon season is associated with sudden changes from marine to brackish water condition in the coastal ecosystems. During this season, significant changes occur in the environmental features of the estuary. The topographic features of the backwater system, tidal currents, freshwater discharge and water circulation are the master factors which play important role in making these estuarine waters a highly complex environment. These master factors are responsible for the distribution of temperature, salinity, dissolved oxygen and other chemical components in the estuary and these in turn govern the distribution of organisms present in the ecosystem.

The annual average rainfall of Cochin is estimated as 3230 mm (Daily weather chart) based on the average of the past ten years; of which nearly 75% occurs during southwest monsoon season (Sankaranarayanan and Qasim, 1969). The monthly rainfall data for Cochin region indicated the onset of southwest monsoon in May 1990. Thus the total rainfall from May-September was 1900 mm while it was 1340 mm only during the normal monsoon season (June-September) constituting 59 and 41.5% of annual average respectively which fall far below the normal rainfall (75%) of this season. The rainfall for June-July (1079 mm) and August-September (261 mm) showed that peak monsoon occurred during the first half of the normal monsoon season (June-July). The intermittent fall during the first and second fortnight of June (228 & 170 mm), followed by a peak in the first fortnight of July (484 mm) and the decrease in the intensity of rainfall during the second half of the season (30-126 mm) have direct or indirect influence on hydrographic parameters and phytoplankton production to a great extent.

The results on hydrographic parameters revealed that water temperature and dissolved oxygen in the euphotic zone (having a mean depth of 1.5 m) did not exhibit any remarkable variation except a slight increase in the South Zone (Station 1). This may be due to the relatively shallowness of the water body, more freshwater flow and relatively less tidal influence (as evidenced from the salinity values). The bottom water temperature showed much variation, with relatively higher values during the first half (June-July) and low values (mean 25.3°C) during the later half (August-September) of the monsoon season. Dissolved oxygen also showed the same trend in distribution with higher values in the euphotic zone and mean value as low as 2.54 ml/l during the second half while it was 3.5 ml/l during the first half of the season. Salinity values were low at surface due to freshwater flow during high and low tide especially during the first half of the season, and the bottom mean values for the first and second half of monsoon were 5.39 and

25.37‰ respectively. Thus temperature, dissolved oxygen and salinity showed vertical gradients with high values of temperature and dissolved oxygen and low values of salinity at surface and the reverse at bottom respectively during south-west monsoon season. Sankaranarayanan and Qasim (1969) have reported the vertical gradient in dissolved oxygen in the Cochin backwater. The undersaturated oxygen values observed in surface water during monsoon season may be due to the utilization of oxygen for the decomposition of dead planktonic organisms. Shynamma and Balakrishnan (1973) have stated that the decomposition would be greater when fluctuations in salinity are wider. The entry of colder sea water may also contribute to the low oxygen values especially at bottom. The presence of high saline water at the bottom with low temperature and low oxygen level during August-September in the study area is a good indication of incursion of upwelled sea water into the estuary during this season, as reported by Ramamirtham and Jayaraman (1963) and later by Shynamma and Balakrishnan (1976).

The nutrient distribution also showed vertical stratification in the case of reactive phosphate, nitrate and nitrite with high values in the surface waters (Table 2). This contradicts the observations made by Sankaranarayanan and Qasim (1969) and Manikoth and Salih (1974) in the Cochin backwater. They have reported increasing trend from surface to bottom. The distribution in general showed a decreasing trend from June to September (Figs. 6-9) with peaks during the first half of the season. Phosphate-P and Nitrate-N values as high as 15.5

and 22.55 µg at/l respectively were recorded at station 1 (Fig. 2) in the south zone and in general, the nutrient values were higher at this station (zone). Perusal of literature reveals that very high concentrations of PO_4-P upto 32.0 µg at/l (Pillai _et_ _al_., 1975) and NO_3-N and NO_2-N to the extent of 30.0 and 3.5 µg at/l respectively (Manikoth and Salih, 1974) have been reported in the Cochin backwater. The presence of higher nutrient values at surface, their relative abundance in the south zone during June-July and the decreasing trend in values from June to September corresponding to the reduction in rainfall confirm that the main source of these nutrients is through freshwater discharge from land drainage during south-west monsoon season.

The estimates of these nutrients in the entire water column of study area having mean depth of 7.5 m showed higher values especially below the euphotic column since the euphotic depth (mean 1.5 m) was very less when compared to the depth of water column below the euphotic zone (mean 6 m). But the column averages per m^3 of water showed higher values in the euphotic zone (Table 12). The mean N/P ratio (1.65) for this season obtained (in the presence of high values of N & P) was due to the unusual high concentration of PO_4-P; and the nitrogen was contributed mainly from nitrates. The very high values of nutrients observed in the estuary especially in the surface waters during the first half of the monsoon season might indicate the influence of excess fertilizers from agriculture and industrial wastes derived from land drainage.

The results revealed the presence of two modes of phytoplankton population during southwest monsoon season. The initial mode observed during the peak monsoon (June-July) was of lesser concentration when compared to the next mode of phytoplankton population observed during August-September when the rainfall was minimum and salinity of water was increasing by greater tidal influence. The initial mode was dominated by species of Coscinodiscus, Ceratium, Rhizosolenia, Navicula and Biddulphia when the salinity of water was less than 4‰ in the euphotic zone; while the next mode was dominated by species of Chaetoceros, Fragilaria, Nitzschia and Pleurosigma during the second half of the season when the salinity was 5-20‰ (Table 13). Species of Coscinodiscus, Nitzschia, Rhizosolenia and Skeletonema were represented considerably in both modes. Qasim et al. (1972) have reported that species of Coscinodiscus can bloom in salinity range of 0.25‰. By the onset of monsoon, the marine species present in the backwater (during summer) become inactive, die, and are added to detritus and they are gradually replaced by the multiplication of brackishwater and freshwater species. These forms appear in large numbers during monsoon and get disappeared by death and decay when freshwater discharge is reduced and salinity of water increased towards the close of monsoon season. These groups of phytoplankters have been recorded by George (1958) in the Cochin backwater.

Since chlorophyll is one of the major indices of the standing crop of phytoplankton, the estimation of chlorophyll pigments and phaeo-pigments along with that of primary productivity is expected to give a general idea of the variation in the magnitude of production. The present investigation revealed the abundance of chlorophyll 'a' than 'b' and 'c' in the estuarine environment which contradicts the observations of Gopinathan et al. (1984) in the Cochin backwater during 1974 that the most dominent pigment in the backwater was chlorophyll 'c'; whereas in the present study, chlorophyll 'c' occupied second place, followed by chlorophyll 'b'. This could be due to the variation in the composition of phytoplankton species from year to year in the backwater environment as a result of changes in the intensity of rainfall. The abundance of chlorophyll 'a' in September when the rainfall was minimum indicated that rainfall and freshwater inflow have negative relationship with the amount of chlorophyll 'a' pigment, and the reduction in rainfall during August-September with relatively higher salinity in the environment would be responsible for the abundance of chlorophyll 'a' concentration during the period under report. The negative relationship with the rainfall tends to lower the magnitude of production during peak monsoon months (June-July). A similar trend was also noticed by Nair et al. (1975).

In the present observation, the richness of chlorophyll 'a' followed by 'c' indicates high productivity in the estuary as stated by Vijayalakshmi (1986) in the Vellar estuary; and the concentration of chlorophyll 'a' always exceeded carotenoid values. This indicates the good physiological state of phytoplankton (Bhargava and Dwivedi, 1974). Generally carotenoids showed an increase corresponding to the magnitude of chlorophyll 'a' and total chlorophylls.

Wright (1964) reported that chlorophyll 'b' was the prominent pigment in freshwater forms such as Euglena and Volvox. The qualitative analysis of plankton in the present study also revealed the dominance of these species in July with highest mean ratio of 'b'/'a' recorded as 0.54 while the average value in the study area was 0.36. These values fall within the range as reported by Vijayalakshmi (1986) in Vellar estuary. The ratio of 'c'/'a' also showed maximum value in July when the water was very turbid. The observations of Bhargava and Dwivedi (1974) indicated that this high ratio might be due to the presence of inactive and dead chlorophylls in turbid waters.

The presence of relatively higher concentration of chlorophyll 'a' and 'b' in the south zone during June-August which can be attributed to the abundance of freshwater algae; the middle zone with higher concentrations of 'a', 'b' & 'c' and barmouth zone with 'a' and 'c' in general, indicate the fluctuations in the distribution of phytoplankton species in the study area. Based on chlorophyll concentrations and primary productivity, middle zone proved to be highly fertile with relatively less ecological impact. The higher mean value of chlorophyll 'b' obtained in the water column below euphotic depth during August-September than in June-July (Table 14) might be due to the sinking or mixing up of water mass from the euphotic zone or it could be due to some other species from the coastal marine environment.

The results also revealed that the secondary peak of total chlorophylls constituted by the phytoplankton production of less saline environment were found to disappear towards the middle of August in the surface waters especially in the middle and barmouth zones (stations 2 & 3) than in the south zone (station 1), and the successive peak of high magnitude of phytoplankters prefering relatively higher salinity occupied the estuary from the second fortnight of August (Figs. 2-5) quite likely from the neighbouring sea since the tidal influence and salinity of water were found increasing simultaneously; whereas in the water column, the initial peak was found to be at the verge of disappearance and the successive peak of high magnitude was found to occupy from the beginning of August (one fortnight earlier than in the surface waters), corresponding to the increase in bottom salinity (Figs. 10 & 13). The reduction in concentration of chlorophylls during the second fortnight of July and first fortnight of August and subsequent increase in the second half with increase in salinity in the environment indicated succession of species.

The chlorophylls were present in higher concentration in the euphotic zone as well as in the water column below the euphotic depth. The estimate of chlorophyll pigments available in the water column below euphotic zone is quite high especially during the second half of the season and they tend to die due to lack of light for photosynthesis and increase the phaeo-pigment concentration.

Distribution of phaeo-pigments followed almost the same trend as in the case of chlorophyll 'a' and total chlorophylls (a+b+c), with two peaks during the southwest monsoon season. The concentration of phaeo-pigments increased with variation in the environmental parameters. Since the sudden variations in the environmental parameters like salinity, temperature and dissolved oxygen at surface waters were not remarkable when compared to the bottom waters, the percentage of phaeo-pigments in relation to total chlorophylls (a+b+c) was less in the surface waters and more in the water column, especially below the euphotic depth indicating that the death rate is higher in the bottom waters. The factors responsible for such increase in the percentage of phaeo-pigments in bottom waters could be the wide fluctuations in the environmental parameters caused by the relatively more tidal influence and sudden incursion of upwelled seawater, lack of light for photosynthesis at the bottom layers, sinking of inactive and dead cells from the upper euphotic zone and partly due to grazing and subsequent exudation by zooplankters.

But, the availability of higher quantities of phaeo-pigments in the euphotic column in proportion to the concentrations of chlorophyll and carotenoid pigments and their relatively low concentrations in the water column below the euphotic depth in general (Table 14) suggest that the concentration of phaeo-pigments is more related to the death of phytoplankton cells of the respective depth zones and the sinking rate could be considerably low in this region because of the water currents caused by the flood flow in the surface layers and mixed semi-diurnal tidal flow especially in the bottom layers. As a result, major quantities of these live and dead cells are transported to the neighbouring ecosystems simultaneously.

The decrease in the initial mode of total chlorophylls by environmental changes simultaneously with the relative increase in percentage of phaeo-pigments in water indicated the mortality of phytoplankton cells (Fig. 4 - first fortnight of July to first fortnight of August).

In general the percentage of phaeo-pigments in total chlorophylls was very high in the water column at station 2 (middle zone) and 3 (barmouth) from August to middle of September due to the sudden change in environment by the incursion of colder highly saline upwelled sea water into the estuary. The percentage was higher in the middle zone than at barmouth due to the wider fluctuation met at this zone, as evidenced from the salinity distribution (Figs. 11 & 12); and it was considerably less at station 1 (South zone) due to its less proximity from the sea as compared to the middle zone. During the last fortnight of this season (second fortnight of September), the estuarine environment became relatively stable by the reduction in the incursion of upwelled sea water into the estuary as observed from the salinity distribution in the column waters of stations 1-3 (Figs. 10-12), when the water had highest concentration of chlorophylls and relatively low values of phaeo-pigments as compared to the previous fortnights in the second half of the season. This indicated a healthy sign of phyto-plankton production with maximum chlorophylls and primary productivity, lesser mortality and better ecological condition at stations 2 & 3 (Figs. 11 & 12). The high level of mortality of phytoplankters as evidenced from the higher concentration of phaeo-pigments observed during the second fortnight of August and first fortnight of September in the water column of middle zone and barmouth zone could be attributed to the sudden increase in salinity values caused by the incursion of upwelled seawater into the estuary.

The rate of primary production also showed in general an increasing trend from June-September, with high production during August-September. The surface waters recorded an average gross production of 0.960 g C/m^3/day while the net production was 0.668 g C/m^3/day constituting 69.6% of gross production. In the euphotic column waters the average gross and net productivity were estimated as 1.349 and 0.815 g C/m^2/day respectively while net production constituted 60.4% of gross production. These values revealed that surface waters were more productive during southwest monsoon season. According to Qasim (1973), 90% of the total production is confined to the topmost layer and maximum occurs either at surface or slightly below.

From the results it is understood that approximately 30% of production in the surface waters and 40% in the euphotic column are utilized at the primary level itself. This observation agrees with the result and statement of Qasim (1970) that net production is 60% of gross production in tropical estuaries. According to Nair et al. (1975), the average rate of production in the surface waters of Cochin backwaters amounts to 0.200 g C/m^3/day for the southwest monsoon season. This value seems to be very less when compared to the present average value. It shows that primary productivity of the backwater has increased considerably in the monsoon season of this year (1990) and this high value could be attributed to the intensity of monsoon with the peak in the first half and lesser intensity during the second half and with intermittent reduction in rainfall observed during June together with nutrient enrichment in the backwater during this season. However, the observations of Joseph and Pillai (1975) revealed higher mean primary productivity in one of the stations in Cochin backwater as 0.830 g C/m^3/day during monsoon season. The above observations reveal that productivity vary from year to year depending on the intensity of rainfall and environmental characteristics of the estuarine ecosystem.

When computed the average gross and net production values for the whole season (4 months), the values amounted to 164.58 and 99.43 g C/m^2 respectively in the study area and it was 164.58 and 99.43 tonnes of carbon/km^2 respectively. Nair et al. (1975) have estimated the annual primary production for the entire Vembanad Lake comprising about 300 sq.km as 1,00,000 tonnes of carbon which is a minimal estimate according to them. Out of this, their observations indicated that southwest monsoon season contributed about 22% only (21,840 tonnes of carbon). While computing the present mean net production value for the entire 300 sq.km (for comparison), the monsoon season in 1990 contributed 29,830 tonnes of carbon amounting to about 30% of their annual estimate for the backwater. This indicated very high productivity in the backwater adjoining Cochin city during this season.

Qasim (1970) suggested that only about 30 g C/m^2/year is used up by zooplankters from the net production leaving large surplus of this basic food in the estuary. Accordingly, about 10 tonnes of carbon/km^2 area (10 g C/m^2) would be consumed by the zooplankters during this season (4 months) out of the estimated net production of 99.43 tonnes of carbon. The surplus production would be utilized by the consumers like herbivorous fishes in the backwater and the other direct link is through detritus feeders like prawns and other benthic communities. As the euphotic zone is considerably less in this ecosystem, a good part of phytoplankton production, while sinking below the euphotic zone could form food of benthic communities, while considerable quantities of these organic matter is transported to the neighbouring ecosystems by tides, flood flow and migration of consumers. Thus the magnitude of primary production in the Cochin backwater is able to sustain a very rich biota of organisms feeding at different trophic levels.

The net/gross production ratio ranged from 0.45-0.95 in the present investigation. These values agree well with the observations of Qasim et al. (1969) for the Cochin backwater (0.55-0.75). Vijayalakshmi (1986) also obtained a similar ratio of 0.5-0.9 in Vellar estuary. The ratio would indicate the physiological state of phytoplankton population and higher values showed the availability of healthy phytoplankton population and also the stability of environmental characteristics of the ecosystem. The low % of net production in gross values obtained during diurnal experiments in the bottom waters especially at high water level during high tide (when exposed to normal light at surface) might be due to the physiological upset and metabolic loss resulted by the sudden change in the environment from the sea to the estuary by tide and from the bottom to surface for the experiment.

Assimilation number in the study area varied between 3.57 and 11.87 with the mean value of 6.81 during this season. Qasim (1973) observed assimilation numbers ranging from 0.6 - 14.8 in Cochin backwater. Such large variations indicated that the entire observed chlorophyll pigments were not photosynthetically active (Qasim 1973). The average assimilation number for the Vellar estuary was 11.3 (Vijayalakshmi, 1986). According to Curl and Small (1965), assimilation number 0-3 indicated nutrient depletion, 3-5 border line nutrient deficiency and 5-12 indicated nutrient-rich waters. According to this, the study area came under the third category during southwest monsoon season.

Studies on seasonal variation in phytoplankton production by Nair _et al_. (1975) in the entire Cochin backwater system indicated that monsoon rainfall may have direct influence on phytoplankton production or through the environmental factors of the ecosystem. While relating the rainfall data, consideration should be given not only to the local rainfall but also to the rainfall of the upstream region from where the catchment is brought into the estuary, since local rainfall alone may have relatively lesser effect on the estuarine ecosystem. However, in the present investigation, rainfall data for Cochin region alone was taken into account since the data for the other concerned regions were not readily available for use.

It would be wiser and reasonable to compare the phytoplankton production in a fortnight with the rainfall data of previous week or fortnight rather than that of the respective fortnight since the multiplication of phytoplankton cells consumes considerable time to reach the level of high magnitude as and when the primary and secondary peaks are concerned. In this context, the relatively higher concentration of total chlorophylls (a+b+c) observed during the second fortnight of June and first fortnight of July in the surface and column waters of all the three stations might be related to the reduction in rainfall of first and second fortnight of June respectively. So also, the decline in the concentration of total chlorophylls to very low value in the second fortnight of July could be very well related to the heavy downpour of rainfall (484 mm) recorded in the previous fortnight. This relationship could be observed in all the three zones (Figs. 2-5 for surface production and Figs. 10-13 for column production). Monthly distribution and abundance of total chlorophylls and primary productivity showed primary peak during the second half of the season (August-September) when the aggregate rainfall was 261 mm as against 1079 mm in June-July. These observations reveal that rainfall beyond an optimum level is not favourable for phytoplankton production in the estuarine environment since heavy rainfall has impact on other environmental factors such as intensity of flood flow, turbidity, light penetration, salinity etc.

However, this relationship with rainfall was not felt much in the fortnightly results obtained from primary productivity experiments during June-July when maximum rainfall was recorded (Figs. 2-4). The irregularity in the primary productivity results during the first half of the season might be attributed to the variations in light intensity by the changing pattern of clouds and overcast sky at the time of incubation on the experiment days.

The relative proportion of total chlorophylls and primary productivity was found to vary much among the stations though the experiments were carried out on the same days (Figs. 2-4). Such irregularities in the presence of same light intensities could be attributed to the abundance and physiological state of the phytoplankton cells in the respective zones. The low productivity values in the presence of higher concentrations of chlorophylls indicate the presence of more inactive cells in the environment. The influence of light on primary productivity is a well established fact and cannot be ruled out. The higher productivity values obtained from the near-bottom waters, when exposed to the normal light during primary productivity experiments (L & D method), indicated that the inactive chlorophylls present in the water column below the euphotic depth became active in the presence of light.

Since the temperature in the euphotic waters did not show much variation in par with the wider fluctuations in phytoplankton production, its relationship on productivity was not significant. Dissolved oxygen in the surface layers also did not exhibit much variation and hence no remarkable relationship with variation in productivity could be noticed during the southwest monsoon season.

Primary productivity in relation to tide gave better results than with the time of sampling. The record of high production at high tide and low at low tide indicated that the main source of phytoplankton production was from the sea than from the upstreams. The results also indicated that although vertical stratification of water mass was prominent during this season, considerable mixing of bottom watermasses with surface waters was felt in this dynamic environment as evidenced from the salinity values, abundance of chlorophylls and primary production in surface waters during high tide.

The relatively higher production observed in the surface waters at stations 2 & 3 than at station 1 could be related to the high tidal influence owing to their proximity to the sea and to the relatively higher salinity values observed in the respective stations (Figs. 2-4). But, in column waters, eventhough mean salinity values were higher, concentration of chlorophylls and primary productivity per m^3 of water did not show proportionate increase since sufficient light was not present for photosynthesis. This indicates that salinity does not stand alone to limit or govern phytoplankton production in the estuary.

The unusual high values of phosphate-P, nitrate-N and nitrite-N recorded during June-July with very low phytoplankton production in terms of chlorophylls and primary productivity and the record of relatively low concentrations of these nutrients in the surface and column waters during August-September with very high production of phytoplankton in terms of chlorophylls and primary productivity (Figs. 2-9) suggest that these nutrients are not responsible for the low phytoplankton production in the first half of the southwest monsoon season under report.

The statistical analysis showed that in the surface waters the variable total chlorophylls gave maximum positive correlation with gross production (C.c - 0.81) followed by carotenoids (C.c - 0.67) and in the euphotic column the variable salinity gave maximum positive correlation (C.c - 0.79) followed by total chlorophylls (C.c - 0.76) (Tables 18 & 19). This shows that salinity is an important factor that influence the primary production in the euphotic column, but in the surface waters its influence on primary production is relatively less. The multiple regression analysis proved that 83% of the variations in production of the surface waters and 86% of the variations in the production of the euphotic column can be explained by the explanatory variables. The rest of the variations may be due to the dynamic nature of the backwater, circulation and mixing process of seawater and freshwater brought about by the semidiurnal tidal rhythm and flood flow which may not be constant all over the estuary.

A close consideration of the foregoing facts indicates that although the factors like rainfall, light, salinity and nutrients have their individual role, it is difficult to pinpoint any one as the limiting or governing factor for phytoplankton production the estuary. It might be a combination of various parameters that is necessary to create an optimum condition for the blooming of these phytoplankters as observed in the second half of the southwest monsoon season and particularly in the last fortnight of this season.

While comparing the fertility of the three zones from the phytoplankton production point of view, although these three zones are treated as good in respect of primary production for this season, the middle zone is considered as the typical and ideal zone with relatively lesser ecological disturbances.

SUMMARY

This dissertation presents the results of investigations carried out on the distribution pattern and abundance of phytoplankton pigments (live and dead) and primary productivity in relation to the environmental parameters in the Ernakulam channel of Cochin backwater during the southwest monsoon season from June to September, 1990.

The significance of phytoplankton production, resume of literature and scope of the study are mentioned under the title 'Introduction'. The description of the study area and methodology in the collection of samples, laboratory analysis and treatment of data are included in 'Material and Methods'.

The findings and conclusions derived from the present study were based on weekly data obtained on monsoon-related hydrographic parameters such as rainfall, water temperature, dissolved oxygen, salinity and nutrients (reactive phosphate, nitrate and nitrite) and phytoplankton pigments such as chlorophyll 'a', 'b' & 'c', carotenoids, total chlorophylls and phaeo-pigments and on primary productivity (gross and net production) from the three fixed stations viz. (1) south zone, (2) middle zone and (3) barmouth zone in the Ernakulam channel of Cochin backwater system between the railway-cum-road bridge in the south to the barmouth at Cochin.

Since the measurements were subjected to diurnal, micro-distributional and experimental sources of variability, individual values of these parameters were not considered (as far as possible) and the data were consolidated to fortnightly and monthly averages for the results and discussion.

The mean depth of the three stations were 5.5, 7.5 and 9.5 m respectively and the depth range along the side of the main channel was 1-5 m. Water was turbid and the euphotic depth varied from 125 cm at station 1 to 175 cm at station 3 and the average euphotic depth for the study area was considered as 150 cm during the period of investigation.

The Ernakulam channel had local rainfall of 1900 mm during the southwest monsoon season and the monsoon started in May during this year. The rainfall data showed an intermittent decline in June, followed by a peak in the first fortnight of July and then showed a decreasing trend in rainfall in the second half of the season. The rainfall for June-July and August-September were 1079 and 261 mm respectively and in total for the season showed a decline during this year when compared to the mean rainfall of Cochin (average of last ten years) for this season.

Water temperature, dissolved oxygen and salinity showed vertical gradients with higher values of temperature and oxygen and lower values of salinity at the surface during monsoon season.

The occurrence of very high saline water with very low temperature and dissolved oxygen values at the bottom during August-September indicated the incursion of upwelled sea water into this estuary during monsoon season.

When the reduction in the intensity of rainfall was noticed from the first fortnight of August, its effect on the backwater was observed after a fortnight by the increase in salinity of water (second fortnight of August). This increase in salinity was more pronounced in the barmouth zone and very less in the south zone.

Nutrients in general showed a decreasing trend in their concentration from June to September in relation to the decrease in rainfall, with very high values recorded during the peak monsoon months. The values were generally higher in the surface waters, especially at the south zone.

The very high concentration of nutrients in the surface waters especially in the south zone during the peak monsoon months (June-July) indicated that their main source was through the freshwater discharge than from the sea or in situ production.

Although the total estimates of nutrients showed higher values in the water column below the euphotic zone (since the depth was more than the euphotic depth), concentration of nutrients per m^3 of water showed higher values in the euphotic column.

The mean N/P ratio of 1.65 in the ecosystem during June-September revealed that this low ratio was due to the occurrence of unusually higher concentration of reactive phosphate. The results also indicated that the nitrogen values were mainly derived from the nitrates in the ecosystem.

Phytoplankton composition showed two modes during the southwest monsoon season. The initial mode was dominated by freshwater algae and species of Coscinodiscus, Ceratium, Rhizosolenia, Navicula and Biddulphia during peak monsoon (June-July), when the salinity was less than 4‰. The next mode of high magnitude was dominated by species of Coscinodiscus, Rhizosolenia, Chaetoceros, Fragilaria, Nitzschia and Pleurosigma during August-September when the salinity of water was 5-20‰.

The concentration of phytoplankton pigments in general showed progressive increase from June to September. Among the pigments chlorophyll 'a' was abundant followed by 'c'. Chlorophyll 'b' was relatively more in the south zone during June and August after peak rainfall in May and July respectively, when the salinity of water was very less.

The distribution of total chlorophylls (a+b+c) in general followed the same trend as that of chlorophyll 'a' in the estuarine ecosystem showing a small peak in June-July and primary peak during August-September.

The decline in the first peak of total chlorophylls during July-August (when the salinity was less) followed by the formation of a secondary peak of high magnitude during August-September (when the salinity was relatively high) indicated succession of phytoplankton species of high salinity tolerance.

In general, when a sudden reduction or peak in the intensity of rainfall was noticed in a fortnight, its influence was reflected on phytoplankton pigment concentration in the next fortnight.

In the case of phaeo-pigments also, a progressive increasing trend was observed from June to September in par with the production trend of chlorophyll pigments with a small peak in the first half and primary peak in the second half of the season.

When high concentration of phaeo-pigments was observed in a fortnight, a reduction in the live pigment concentration could be seen in the next fortnight; and when the phaeo-pigment was lesser in magnitude, an increase in the live chlorophyll concentration was noticed (during August-September). Such decrease in the concentration of total chlorophylls and the relative increase in the percentage of phaeo-pigments in water indicated the mortality of phytoplankton cells in the estuary.

Primary productivity also showed an increasing trend from June to September as in the case of pigments, with high rate during the second half of the season. In general, the surface waters were more productive during this season. The estimated net production in the Ernakulam channel was 99.43 tonnes of carbon per sq.km for the season (4 months) and the mean net productivity was 60% of gross production.

The wide fluctuations observed in the assimilation number indicated that the entire chlorophylls were not photosynthetically active; and higher mean values also indicated the fertility of water with nutrients.

In surface waters, total chlorophylls gave high positive correlation with gross primary production (C.c - 0.81). In the euphotic column, the relative proportions of total chlorophylls and primary productivity was found to vary among the stations. Such irregularities in the presence of same light intensities could be attributed to the physiological state of the phytoplankton cells. The low productivity in the presence of higher concentrations of chlorophylls indicated the presence of more inactive cells in the environment.

The bottom water samples when exposed to normal sun-light in productivity experiments gave higher values indicating that the bottom waters were potentially productive in the presence of light.

Since temperature and dissolved oxygen content in the surface waters did not show remarkable variation in par with the wider fluctuations in phytoplankton production, their relationship on phytoplankton productivity was not significant in the estuary during this season.

Primary productivity in relation to tides gave better results than with time in the diurnal experiments. The record of high production at high tide and low at low tide indicated that the main source of phytoplankton production was from the sea through the tidal influence than from the upstreams.

The results also revealed that although vertical stratification of watermass was prominent during this season, considerable mixing of bottom watermass with surface layer was felt in this dynamic environment as evidenced from the increase in salinity values, abundance of chlorophylls and primary production in surface waters during high tide.

The relatively higher salinity in the column waters (August-September) and higher nutrient concentration in surface waters (June-July) did not show proportionate increase in primary production in the respective waters. Although salinity was found to influence phytoplankton production in the euphotic column as per statistical analysis, its influence on primary production was found to be relatively less in surface waters where the highest production was obtained.

The very high concentration of nutrients with low phytoplankton production observed during June-July revealed that the nutrients were not the limiting factor to govern phytoplankton production in estuary.

From the above results, the present study reveals that the rainfall beyond an optimum level is not favourable for phytoplankton production in the estuary since heavy rainfall has greater impact on the other environmental factors such as the intensity of flood flow, tidal influence, turbidity, light penetration and salinity of water, eventhough enormous quantity of nutrients are brought into the estuary by the consequent freshwater discharge from land drainage.

The high values of phytoplankton production obtained in the present investigation are more related to the low intensity and intermittent reduction/gap in the rainfall and its influence on the hydrographic factors in the estuarine ecosystem.

A close consideration of the foregoing facts indicates that it might be the combination of various parameters that is necessary to create an optimum condition to favour phytoplankton production. The environmental condition prevailed in the second half of the monsoon season and particularly in the last fortnight (later half of September) of this season provides an optimum condition for high primary production during southwest monsoon season.

Among the three zones, south zone is considered as the relatively less productive region, characterised by relatively elevated bottom topography with higher water temperature, oxygen and nutrient concentrations and with relatively low tidal influence, salinity, phytoplankton pigments and primary productivity; while middle zone is considered as the typical and ideal region for phytoplankton production with relatively lesser ecological disturbances during the southwest monsoon season.

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